REPORT

METROPOLITAN SEWERAGE COMMISSION

OF

NEW YORK

1914

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Presented by

Mr. Soper

October 1914.

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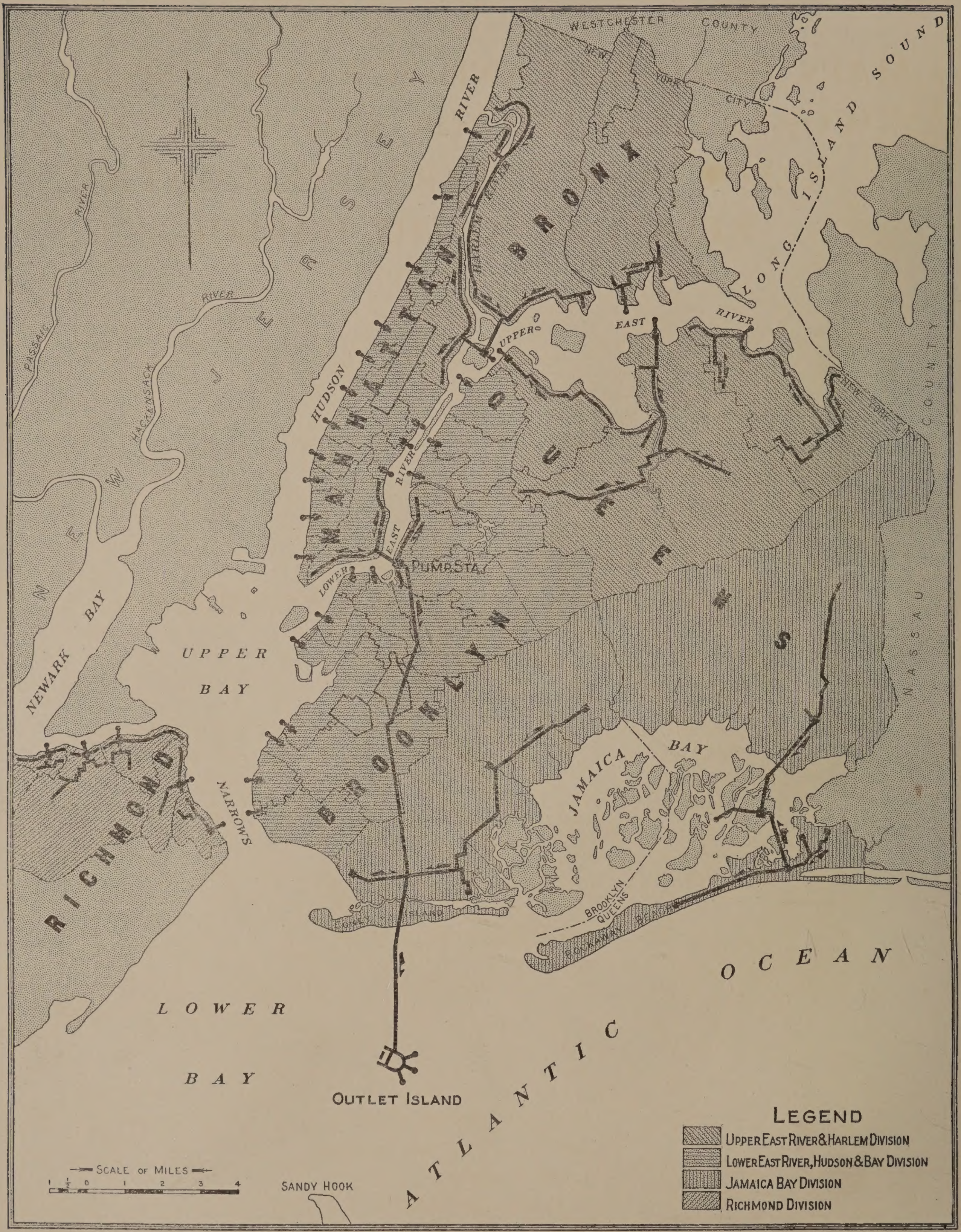

FRONTISPIECE

Main Drainage and Sewage Disposal Works Proposed for New York City.

MAIN DRAINAGE AND SEWAGE DISPOSAL WORKS PROPOSED FOR NEW YORK CITY REPORTS OF EXPERTS AND DATA RELATING TO THE HARBOR

REPORT

OF THE

METROPOLITAN SEWERAGE COMMISSION

OF NEW YORK

Appointed under Chapter 639, Laws of 1906, amended by Chapter 422, Laws of 1908,
Chapter 200, Laws of 1910, and Chapter 332, Laws of 1913, of New York State

APRIL 30, 1914

GEORGE A. SOPER, President
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LETTER OF TRANSMITTAL

NEW YORK, April 30, 1914.

Honorable JOHN PURROY MITCHEL, Mayor of the City of New York,
Executive Chamber, City Hall, New York City.

SIR: The report of the Metropolitan Sewerage Commission which is submitted herewith recommends a system of main drainage and sewage disposal for New York City, to be built in progressive stages.

This report is the third bound volume issued by the Commission to describe its investigations and its opinions and recommendations. In addition there has been issued a series of seventeen preliminary reports and various interim reports, copies of which have been distributed among the officers of the New York City Government. A list of the reports, with the dates of issue, will be found at the end of the present volume. There is also appended a list of the assistants and experts employed. The membership of the Commission has remained unchanged from the reorganization of the board in January, 1908, to April 30, 1914.

Respectfully submitted,

METROPOLITAN SEWERAGE COMMISSION OF NEW YORK:
GEORGE A. SOPER,
JAMES H. FUERTES,
H. DEB. PARSONS,
CHARLES SOOYSMITH,
LINSLY R. WILLIAMS.

FOREWORD

It will be of assistance in examining the following report to note that it is divided into four parts.

Part I is a summary of the work done from 1906 to 1914.

Part II describes the plans for main drainage and sewage disposal works which the Commission recommends the City of New York to construct for the protection of the harbor.

Part III contains reports of experts consulted by the Commission, including five critical reports and four reports upon special topics, together with digests of these reports and explanatory matter relating thereto.

Part IV contains data relating to the protection of the harbor, including analytical results not previously published, corrected statements with respect to tidal flow, a discussion of the present status of sewage disposal and practical examples of main drainage and sewage disposal works of various large cities.

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PART I.

Summary of the Work 1906-1914

PART I

Summary of the Work 1906-1914

With the making of this report and in accordance with instructions from the Legislature, the Commission submits to the Mayor a general plan of main drainage, sewage collection and disposal for the whole city, and recommends that a special commission be created or designated to build and maintain the works. The plan is sufficiently definite to show the nature, extent and approximate cost of the works. Such detailed studies of design as may be necessary before the final estimates and contracts are prepared can appropriately be made by those who are intrusted with the construction.

To place the construction in the hands of a commission to be created or designated for the purpose is in accordance with the precedent followed by the city heretofore in connection with its water supplies and subways. The Metropolitan Commission does not seek authority for carrying its recommendations into effect.

The System Recommended

The system recommended consists largely of intercepting sewers, running approximately parallel to the water front, to collect the sewage from the local sewerage systems to a number of centrally situated disposal plants where sufficient of the impurities can be removed to permit the effluent to be discharged into the waters without danger or offense. To facilitate the diffusion and assimilation of the sewage materials by the water, it will be desirable to place the outlets at the bottom of the deep and swiftly-flowing channels.

The system of main drainage which the Commission recommends is presented for adoption by the city both as a plan and policy for future construction and should be carried out in successive stages and not as one undertaking. The immediate construction of the whole scheme is not necessary from a sanitary standpoint. Such parts of the system as are needed for the immediate future should be taken in hand at once and the remainder built as required. The plans are sufficiently flexible to permit of the adoption of any discoveries or improvements in the art of sewage disposal which may be made in the future.

When complete, the works will constitute a systematic and well co-ordinated scheme of main drainage for the whole city which will utilize the absorptive capacity of the harbor waters to the greatest extent consistent with due regard to the public health and welfare.

Scope and Legal Authority

The authority and instructions in accordance with which the Commission's work has been done are to be found in four acts of the Legislature of the State of New York. Of these, Chapter 200 of the Laws of 1910 and Chapter 332 of the Laws of 1913 merely extended the life of the Commission. Chapter 422 of the Laws of 1908 continued the Commission from May, 1909, to May, 1910, placed the compensation of the Commissioners on a salary instead of a per diem basis and authorized the Board of Estimate and Apportionment of New York City to provide the means for carrying out the legislature's instructions in a sum not to exceed $75,000 in any one year.

Aside from the foregoing, the authority and instructions of the Commission are contained in Chapter 639 of the Laws of 1906. This act required the Commission to continue the work of the New York Bay Pollution Commission which was established by Chapter 639 of the State Laws of 1903, and extend that work so as to include the following duties:

1. To make further investigations into the present and probable future sanitary condition of the waters of New York bay and other bodies of water within or adjacent to the several boroughs of New York City and neighboring districts.

2. To consider and investigate the most effective and feasible means of permanently improving and protecting the purity of the waters of New York bay and neighboring waters, giving attention particularly to the following subjects:

(a) Whether it is desirable and feasible for New York City and the municipalities in its vicinity to agree upon a general plan or policy of sewerage and sewage disposal which will protect the waters of New York bay and vicinity against unnecessary and injurious pollution by sewage and other wastes;

(b) What methods of collecting and disposing of the sewage and other wastes which pollute, or may eventually pollute, the waters contemplated in this act are most worthy of consideration;

(c) Whether it is desirable to establish a sewerage district in order properly to dispose of the wastes, and adequately protect the purity of the waters, contemplated in this act, and if so, what should be the limits and boundaries of this sewerage district;

(d) What would be the best system of administrative control for the inception, execution and operation of a plan for sewerage and ultimate sewage disposal of a metropolitan sewerage district; whether by the action of already existing departments and provisions of government, by the establishment of separate and distinct sewerage districts and permanent commissions of each state, by one interstate metropolitan sewerage district and commission to be established by agreement between the two States, this agreement if necessary to be ratified by congress or by other means.

3. To co-operate with any duly authorized body or commission having similar authority in the State of New Jersey in the joint investigation and consideration of the various subjects specified in this act.

4. To submit to the Mayor a full and complete report of the investigations, conclusions and recommendations.

To facilitate the work intended, the Commission was given all the powers of committees of the State Legislature, authority to administer oaths, subpoena witnesses and take testimony. Power was also given to engage engineers, chemists, bacteriologists and other assistants and to incur such other expenses as might be necessary.

Upon the termination of the Commission's work, its data and other effects were required to be turned over to the Board of Estimate and Apportionment of New York City.

In a court decision rendered in December, 1908, the Commission was declared to be a State body. This judgment was rendered in a suit brought to determine whether the Commission had a right to fix the salaries of its employees independently of the provisions of the New York City Charter.

Briefly stated, the Commission was a temporary investigating and advisory board appointed by the Mayor of New York City in accordance with mandatory legislation by the State. The Legislature specified the work to be done and conferred broad powers for the accomplishment of the desired results. The City of New York granted the Commission appropriations aggregating $265,000, this money being voted by the Board of Estimate and Apportionment from time to time after fully investigating the uses to which it was to be put. On three occasions the Commission was continued by the Legislature at the instance of the Mayor of New York, the original period of existence of three years being extended to ten years. After eight years, the Commissioners resigned, stating that their work had been accomplished and that it was the unanimous opinion of all who had a thorough knowledge of the conditions that the time had come to provide for the construction and maintenance of the necessary works.

Work Reported to May, 1910

The questions raised by the Legislature were answered in a report dated April 30, 1910. The report stated that the Commission had undertaken to establish the facts attending the discharge of sewage in the metropolitan district, to determine the extent to which the resulting pollution was injurious to the public health and welfare and to ascertain what it would be necessary to do in order to meet the reasonable requirements of the present and future. A study had been made of the capacity of the waters for harmlessly assimilating sewage. The sewerage systems of New York and other cities within twenty miles of the New York City Hall had been examined and estimates made of the population and quantities of sewage discharged from the houses and streets by the human and animal populations. Careful estimates of the future population had been made and, particularly, its location and density. Experimental studies had been conducted to determine the possibility of diffusing and disposing of sewage through the waters of the harbor without offense or danger to the public welfare. Tests had been made to determine the extent to which public bathing places and shellfish beds were polluted by sewage. An investigation of the tidal phenomena of the harbor had been carried on in co-operation with the U. S. Coast and Geodetic Survey. After ascertaining the essential details of various trunk sewer projects which threatened to add materially to the pollution of the harbor, the Commission had expressed an adverse opinion on the discharge of untreated sewage from these trunk sewers. An examination into the legal jurisdiction exercised over the harbor waters had been undertaken in order to aid in determining the best form of administration for a comprehensive system of sanitary conservancy.

At the instance of the Commission and in accordance with the legislative acts which provided for its creation, communications were twice sent by the Secretary of State of New York to the Governor of New Jersey inviting New Jersey to co-operate in the work which the Commission was performing. These invitations were without result. The report of 1910 was a volume of 550 quarto pages.

The recommendations which the Commission made were such as had been found successful in other populous centers in Europe and America. They were to the effect that the metropolitan territory should be divided into sections with boundaries to be determined partly by the quantities of sewage produced, partly by the facilities which existed in the several localities for disposing of the wastes in a sanitary manner and partly by considerations of cost.

No single system of conduits to collect the sewage of the whole district and carry it to one point for disposal was considered practical. To a considerable extent purification works embodying the principles of sedimentation, screening and filtration should be employed. There should be prepared an outline plan to which all future sewerage works should conform so far as that work related to the disposal of sewage and there should be plans drawn in some detail for the disposal of the sewage of individual districts. This program involved for the immediate future no expenditure or commitment of the City or State beyond the expenses of the commission to prepare the plans.

A large part of the sewage discharged into the Harlem river and neighboring waters should be intercepted and taken elsewhere for disposal in order to do away with the existing nuisances. Special detailed studies should be made for improved sewerage and sewage disposal for the portions of the Boroughs of Queens and Brooklyn bordering on Jamaica bay and the East river at the entrance of Long Island Sound with reference to plans for the interception of sewage and a determination of the kind and degree of the purification required.

Plans should be prepared as soon as practicable for the reconstruction of the sewers of Manhattan on the separate plan. The new plans should preserve for use the existing sewers to as great an extent as possible.

With respect to projects for large trunk sewers to discharge the sewage of more or less inland communities into New York harbor, an adequate degree of purification should be insisted upon under a form of agreement which could be legally enforced. The suit of the State of New York against the Passaic Valley Sewerage Commissioners and the State of New Jersey should be pressed, to the end that proper provision might be made to protect the public welfare against the pollution which the commission considered likely to result in spite of an agreement entered into in 1910 between the United States Government and the Passaic Valley Sewerage Commissioners as to purification.

Great care should be exercised in the location of public bathing establishments to avoid unsafe localities and the free floating bathing establishments around the water front should be gradually abolished, properly planned bathing places supplied with pure water being substituted therefore.

The methods of designing and constructing sewers in the metropolitan district should be made standard, where feasible. Closer co-operation should be effected between the departments and bureaus concerned with the construction and maintenance of the sewers of New York. Legal steps should be taken to give the inspectors of the Bureaus of Sewers of New York the right to enter upon property for the purpose of inspecting the sewer connections of houses in order to protect the sewers against acids, hot liquids, steam and other injurious trade wastes.

In conclusion, the Commission stated that it had formulated a general plan or policy by which the sanitary condition of the harbor could be permanently protected and improved. It recommended that the duty of carrying out this policy be placed in the hands of a special board of Commissioners. The first duty of the Commission proposed would be to utilize the information which had been collected and plan the necessary work.

WORK REPORTED FROM MAY, 1910, TO AUGUST, 1912.

Upon receipt of the Commission's report of 1910, the Mayor requested the Commissioners to continue to serve in order to extend the investigations and prepare plans and the legislation necessary to continue the Commission for three years was passed. Delays incurred owing to the performance of work not anticipated and it being found that the Commission could not finish its final report before May, 1913, the Mayor again had the life of the Commission extended by the Legislature.

The work done from 1910 to 1914 was chiefly confined to the City of New York and that part of the harbor which lay wholly or in part within the New York State boundary. The Commission proceeded to lay out a general plan of main drainage and sewage disposal for New York City in accordance with the information and opinions derived from the preceding investigations.

Before the completion of a definite project of main drainage and sewage disposal and before any public announcement of the plan, the engineer in charge of the sewers of the borough in which the proposed works would be located was invited to criticise the plans. This invitation was always accepted and, in some cases, material modifications in the original plans were made in order to meet the suggestions of the local authorities. Works, substantially as recommended in the present report, were announced for the City of New York, this announcement being made in the form of printed preliminary reports with tables of cost and other data and accompanied by lithograph maps and profiles showing the approximate location, size, elevation and capacity of the collectors and interceptors, the location of the disposal works and outfalls and other material.

In August, 1912, the Commission published a report in the form of a bound volume of about 450 pages which contained a description of the present sanitary condition of the harbor and the "degree of cleanness" necessary and sufficient for the water and the results of analytical examinations of the harbor waters and deposits from the harbor bottom. In describing the sanitary condition of the harbor, the volume and circulation of the water was dealt with and an account given of the composition and volume of the sewage which was discharged into the harbor, the appearance of the water, the phenomena of digestion and mechanical transportation of the sewage particles, the state of the water as shown by the dissolved oxygen and the intensity of pollution as indicated by bacterial and microscopical analyses.

The study of the degree of cleanness necessary and sufficient for the water was taken up largely for the Board of Estimate and Apportionment which had been advised by consulting experts, after an investigation, that the city should seek to maintain 70 per cent. of the saturation value of dissolved oxygen in the water and the Board desired to have a special commission created to make a further investigation and report on this subject. The Metropolitan Sewerage Commission's offer to engage experts and make a report upon the proper degree of cleanness was accepted and the 1912 report contains the Commission's opinion, a summary of the opinions of the experts and the reports in full of the eight experts who were called upon.

The analytical data which were published in the 1912 report were shown in the form of tables, maps and diagrams, all carefully co-ordinated to facilitate examination.

The Final Report

Among the reports not otherwise described here were Preliminary Reports VIII to XVII, printed and distributed between November, 1913, and April, 1914. These reports with additional matter are brought together in this final report of the Commission.

A large amount of work has been done by the Commission which has not and cannot well be reported upon without exceeding reasonable limits of expense. Some of this work has been done in the chemical and bacteriological laboratories which the Commission has continuously maintained since 1908. Other investigations have covered special engineering topics, such as dredging and the preparation of alternative plans for the collection and disposal of the sewage. Practically all of these studies have been recorded in the form of reports and are among the extensive, systematically arranged records in the Commission's office.

Experts Consulted

Assisting the Commission in the conduct of its investigations and in the preparation of its projects have been a large number of engineers, chemists and bacteriologists. Throughout its work the Commission has followed the policy of inviting the best qualified experts obtainable to contribute criticism, both constructive and destructive, the intention being to make the investigations represent the broadest, most valuable and authoritative treatment of New York's sewage problem which could be obtained.

Following is a list of the professional consultants engaged by the Commission at various times between October 7, 1908, and January 14, 1914:

W. E. Adeney, Sc.D., F.I.C., Consulting Chemist, Dublin, Ireland.

Charles V. Chapin, M.D., Sc.D., Superintendent of Health, Providence, R. I.

George E. Datesman, C.E., M. Am. Soc. C.E., Bureau of Surveys, Philadelphia, Pa.

Harrison P. Eddy, B.S., M. Am. Soc. C.E., Consulting Engineer, Boston, Mass.

Desmond Fitzgerald, Past President, M. Am. Soc. C.E., Consulting Engineer, Brookline, Mass.

Gilbert J. Fowler, Sc.D., F.I.C., Superintendent, Sewage Disposal Works, Manchester, England.

George W. Fuller, B.S., M. Am. Soc. C.E., Consulting Engineer, New York City.

Augustus H. Gill, Ph.D., Professor of Gas Analysis, Massachusetts Institute of Technology, Boston, Mass.

X. H. Goodnough, C.E., M. Am. Soc. C.E., Chief Engineer of the Massachusetts State Board of Health, Boston, Mass.

Rudolph Hering, Sc.D., M. Am. Soc. C.E., Consulting Engineer, New York City.

Karl Imhoff, Dr. Ing., Chief Engineer, Sewer Department, Emschergenossenschaft, Essen, Germany.

Floyd J. Metzger, Ph.D., Professor of Analytical Chemistry, Columbia University, New York City.

William P. Mason, C.E., M.D., M. Am. Soc. C.E., Professor of Chemistry, Rensselaer Polytechnic Institute, Troy, N. Y.

Samuel Rideal, Sc.D., F.I.C., Consulting Chemist, Westminster, London, England.

William T. Sedgwick, Ph.D., Sc.D., Professor of Biology and Sanitary Science, Massachusetts Institute of Technology, Boston, Mass.

F. Herbert Snow, M. Am. Soc. C.E., Chief Engineer, State Department of Health, Harrisburg, Pa.

J. H. Stebbins, Ph.D., Microscopist and Chemist, New York City.

C.-E. A. Winslow, M.S., Curator, Department of Health, American Museum of Natural History, New York City.

John D. Watson, M. Inst. C.E., Engineer, Birmingham, Tame and Rae District Drainage Board, Birmingham, England.

W. F. Willcox, Ph.D., Professor of Statistics, Cornell University, Ithaca, N. Y.

In arriving at a conclusion upon the subject of administration, a recommendation as to which was one of its specified duties, the Commission had the benefit of the views of a number of citizens who, from official position or other practical experience, are particularly well qualified to advise. The number included Ex-Mayors Seth Low and George B. McClellan, also Messrs. Lawson N. Purdy, Robert W. DeForest, Henry R. Towne, E. H. Outerbridge, George L. Rives and Charles Strauss.

Need of Immediate Action.

As to the urgency of providing a system of main drainage and sanitary sewage disposal, the Commission and its advisers strongly recommend that steps at once be taken to correct the evils which exist. Even if corrective measures are begun immediately, it will necessarily be some years before the works can be completed and their benefit can be realized.

At the present time the crude sewage of a population of over 6,000,000 persons is discharged through several hundred outlets into the harbor without purification, regulation or control of any kind. The discharges, all of which take place at the shore line or beneath the docks and piers, discolor the water, pollute the shores, produce offensive deposits and cause solid matters, plainly recognizable as of sewage origin, to float about in plain sight. Bathing and the taking of shellfish for food are no longer safe north of the Narrows.

The pollution, objectionable as it is at the present time, is rapidly increasing. Within the next thirty years the population will be about double what it is to-day and the quantity of sewage will increase in proportion.

The pollution is most objectionable in summer when it is desirable that the water should be cleanest; it is most intense in those sections where the density of population and the congestion of water traffic are greatest.

The Commissioners feel confident that their recommendation to place the disposal of New York sewage under a special commission will prove to be a measure of economy, since this concentration of responsibility for the sanitary disposal of the sewage will insure an orderly and well co-ordinated development of the City's main drainage works and prevent either the piecemeal construction of works intended to improve intolerable local conditions or unnecessarily comprehensive and expensive main drainage schemes.

The members of the Commission feel that they cannot state the need of improvement too strongly. The public has been made aware of the situation through the numerous reports which the Commission has issued from time to time. Among great cities, New York is practically alone in not possessing either a system of main drainage and sewage disposal or a plan and policy for the sanitary conservation of its water highways.

PART II.

Plans for the Protection of the Harbor

PART II

Plans for the Protection of the Harbor

CHAPTER I

PRELIMINARY CONSIDERATIONS

In a report issued by this Commission April 30, 1910, it was recommended that a sewerage district and commission be created for that part of the States of New York and New Jersey whose natural drainage was directly tributary to New York harbor. The studies which had been made indicated that all the territory within about 20 miles of the New York City Hall, embracing about 700 square miles in the two States, should be included. This entire district had been under investigation and a boundary for the territory had been provisionally established in accordance with the natural water sheds and with regard to the distribution of population. The district extended to the village of White Plains, N. Y., to the north, to the mouth of the Raritan river, N. J., on the south and from the easterly limits of New York City far enough west to include the municipalities of Paterson, Summit and Perth Amboy, N. J. About 90 municipalities lay within this territory.

Dividing the district about equally in a general north and south direction is a line separating New York from New Jersey. Inasmuch as the interstate boundary passes for some miles through the center of the harbor, no plan for protecting these waters can be carried out with satisfactory effect without some form of coöperation.

Coöperation between the two States in devising a comprehensive plan or policy for protecting the harbor against excessive pollution has been sought by New York without effect. The legislative bill providing for the creation of the Metropolitan Sewerage Commission of New York authorized and directed this body to act in concert with a similar board to be created by New Jersey. To this end an invitation was twice extended to the Governor of New Jersey by the Secretary of State of New York before the year 1910. In the absence of coöperation, investigations of the conditions of sewerage and sewage disposal in the entire metropolitan district were carried on by the New York Commission for four years. The results of these studies have been made freely available to the people of the two States by the publication of the report of the Metropolitan Sewerage Commission of New York in April, 1910.

For the three years following the publication of its report of 1910, this Commission confined its attention to that part of the metropolitan sewerage district which lay within the State of New York, the reason for restricting its attention to this part of the district having arisen mainly from a change in the nature of this Commission's work. Occupied before 1910 with the collection of data relating to the conditions of sewerage and sewage disposal as existing up to this time, this Commission's attention was subsequently given to the work of laying down the essentials of an improved plan of main drainage and sewage disposal for New York City.

In laying out an improved system for the disposal of the sewage of New York City, this Commission has received assistance from the sewer bureaus of New York and from various departments and officials of the metropolis whose aid has been requested. The plans have been largely based upon information thus obtained and the various projects have received the benefit of criticism from the city officials charged with the duty of maintaining the local drainage systems in the various parts of the city. As soon as plans for any part of the territory have been brought to a reasonable state of maturity, they have been issued by this Commission in the form of a preliminary report in order that the public might be informed as early as possible and such modifications might be made in the plans for local drainage as would be necessary in order to conform with the larger projects of main drainage.

The total number of preliminary reports leading up to or describing works has been six. The projects announced in the preliminary reports are brought together in the following pages with such modifications as further study and criticism have seemed to make desirable.

Of the six preliminary reports, the first was concerned with the possibility of collecting all the sewage of New York City to a central point for disposal.

The second preliminary report described the four principal drainage divisions in that part of the metropolitan sewerage district which lies in New York State.

The third preliminary report described a study of the collection and disposal of the sewage of the Jamaica Bay Division.

The fourth preliminary report was on the collection and disposal of the sewage of the Upper East River and Harlem Division.

The fifth preliminary report dealt with the collection and disposal of the sewage of the Richmond Division.

The sixth and final preliminary report describing works recommended a plan for the collection and disposal of the sewage of the Lower East River, Hudson and Bay Division.

THE POSSIBILITY OF COLLECTING THE SEWAGE TO A CENTRAL POINT FOR DISPOSAL.

The benefits which would accrue from collecting all the sewage of New York City into one complete system of main drainage and pumping it out to sea are so apparent, and this plan has been so frequently suggested by engineers and others who recognize the need of stopping the pollution of the harbor, that this Commission has given serious attention to the practicability of the project. There are many ways in which this plan could be carried out and the four most promising forms of the general project have been considered. It may be said at the outset that it is within the range of engineering ability to carry out any of them, but this Commission considers that the benefits which would be secured would not be sufficient to justify their cost. Other and more economical ways exist for sanitating the harbor.

The point most suitable for the outlet of the sewage would depend upon the quantity of sewage to be disposed of and the uses to which the neighboring shores of the sea might be put. The larger the quantity of sewage, the farther the outlet should be from land. The farther the outlet is located from the shore, the more costly the undertaking would become. It would be necessary to carry the outlet a long distance from the shores if a large volume of sewage was to be discharged in crude condition, since the coast line within 100 miles of New York in either direction is composed exclusively of sandy beaches which are the resort of large numbers of persons during the summer months. Under any circumstances it would not be feasible to carry the outfall of a sea-going tunnel more than about three miles from the land because of the increased depth of the water. Other conditions which would affect the location of the outfall would be the condition of the sewage with respect to the solid matter contained, the state of the sewage with respect to putrefaction, the force and direction of the tidal currents with regard to the shores and the mouth of the harbor, and the uniformity and intermittency of discharge.

The volume of sewage which would have to be disposed of in case all the dry-weather flow were to be discharged at sea would be very great. Careful estimates of population and quantities of sewage which will be produced in the year 1940 indicate that there will be 1,330,000,000 gallons of sewage per twenty-four hours. Table I shows the estimated population of New York City for 1940; the present population is as enumerated by the United States Census of 1910.

TABLE I

Estimated Volume of Sewage Flow in New York City in 1940. See Report of the Metropolitan Sewerage Commission, Dated April 30, 1910

BOROUGH.	Estimated Population in 1940.	Estimated Volume of Sewage Flow in 1940.	Corresponding Volume of Sewage Flow in Gals. per Capita per 24 Hours.
	See Report of 1910, page 144.	See Report of 1910, page 146. Mgd.*	
Manhattan	3,600,000	583	162
The Bronx	1,200,000	159	132
Brooklyn	3,200,000	426	133
Queens	870,000	138	159
Richmond	130,000	24	185
Total	9,000,000	1,330	148

*Million gallons per day of 24 hours.

The estimates of population and sewage flow contained in Table I are revised from the figures which originally appeared in the report of this Commission, dated April 30, 1910. When that report was being prepared, the United States census for 1910 had not been completed. Estimates made by this Commission indicated that the population was about 4,600,000, whereas enumeration by the Census Bureau showed it to be slightly greater, or 4,766,883. In view of the fact that the city was growing more rapidly than had been assumed by the Commission, the estimates for the population of New York for the year 1940 had to be corrected. In place of a population of 8,660,100 which had been forecasted in the report of April, 1910, the revised forecast became, roundly, 9,000,000.

The first estimates of the sewage flow for 1940 were 1,580,000,000 gallons, and this figure was published in the report of April, 1910. With more definite knowledge of the population in 1910, and with better information concerning the probable total water consumption as studied by the Board of Water Supply, this Commission's figures for sewage flow in 1940 were revised to 1,330,000,000 gallons per twenty-four hours. How great is this volume of sewage can be understood from the fact that it would equal a stream 10 feet deep and 46.7 feet wide flowing at the rate of 3 miles an hour.

The state of the sewage with reference to putrefaction would probably neither favor nor hinder its prompt disappearance. The largest solids would be removed from the sewage by screens for the protection of the pumps which would be required to force the sewage to the outlet, and much solid matter would be broken up by the passage of the sewage through the sewers, so that the matters left in suspension would consist of very finely divided particles and material in the colloid state. The sewers would be so long and, consequently, the time taken by the sewage to reach the outlet would be so great, that the sewage would be in a state of decomposition by the time it reached the outlet and would, therefore, be much more offensive than fresh sewage. In consequence of this fact the water in the vicinity of the outlet would be more offensively polluted than it would be were the sewage to be discharged in fresh condition. The oxygen would almost certainly be entirely gone from solution in the sewage and there would be an immediate and heavy demand upon the dissolved oxygen in the sea water.

Just how far the outlet would be from shore would not be susceptible of exact determination. From six to ten miles seems not too great a distance in view of the circumstances and yet it would be difficult, if not impracticable, to build the outfall at such a distant point by any methods of engineering construction which have thus far been anywhere employed.

CONTINUOUS DISCHARGE AT SEA

Experience shows that the sewage would mingle slowly with the sea water. It would in all probability rise in a column from the outlet at the bottom and flow to the top, there to spread out and move away under the influence of the tidal currents, its destination as sewage being determined partly by the tidal movements, partly by the force and direction of the wind and partly by the intermixing action of the waves.

Studies made by this Commission indicated that the currents of the ocean midway between New York and New Jersey and about 15 miles from shore sometimes traveled at a rate of 2 miles per hour under normal conditions of wind and tide. When garbage was dumped at sea near this point in the year 1906 there was a distinct fouling of the shore lines over a distance of 50 miles from New York along Long Island, and for 70 miles along the shore of New Jersey. Wind undoubtedly had an effect upon this floating refuse, but wind would also have an effect upon the movement of sewage. Wind moves the whole surface of the water upon which it blows, as has been observed by this Commission in studying the behavior of sewage in Upper New York bay.

An examination of the depths of water along the New York and New Jersey coast lines, as recorded upon the official charts of the United States Coast and Geodetic Survey, shows that there is no point available at a distance of 10 miles from shore to which a sea-going tunnel could well be built. The bottom is, for the most part, sandy, so that the tunnel would have to be built with compressed air. The depths required would exceed 120 feet, which is about the limit at which it is practicable for men to exist. Unless the outfall was located at an island, the tunnel would have to be built entirely from shore, no shafts being possible between the land and the point of outfall. This would make the construction of the tunnel a slow and costly undertaking. It is obvious that there would be serious difficulty in the construction of any long tunnel to sea. It is not clear how the outlet should be constructed in order to resist the destructive force of the great Atlantic storms. Storms of great violence occur throughout the winter season in this region and any structure which rose considerably above the bottom would have to be built in a massive way if it was to be permanent. Such structures as the intake cribs built for the supply of water to the cities on the Great Lakes could scarcely be constructed or maintained in the Atlantic, where the storms are very violent, and where there is usually a pronounced ground swell in calm weather. If the outlet were built merely as an opening through the bottom of the sea, it would appear to be necessary to protect it in some manner against the shifting movement of sand which is believed to move in great quantities along the bottom of the New Jersey and Long Island shores. Such an outlet would be difficult or impossible to examine or repair.

Discharge at Sea on Outgoing Tidal Currents

The length of the sea-going tunnel could be greatly shortened if the sewage could be stored temporarily on shore and discharged only on out-going tidal currents. In this case the full benefit of the transporting power of the water could be utilized to carry the sewage matters as far away from the land as possible. Under these circumstances it would seem reasonable to locate the outlet within about 5 miles from shore. A point from which it would be suitable to build the tunnel would be in the vicinity of Rockaway Point, and in this location storage basins should be situated to collect the sewage and hold it until outgoing currents occurred to carry it away. Because of the necessity for discharging only at certain hours, the tunnels would have to be larger or more numerous than would be required if the discharge took place continuously.

Assuming that the quantity of sewage to be disposed of was 1,330,000,000 gallons per day, and that it would be discharged in two periods of four hours each, the storage basins and pumping station which would be required would have to cover an area of about 125 acres. The depth of the storage basins would be 25 feet. The tunnels would be four in number and 18 feet in diameter each. The tunnels would run parallel to one another until near their outer ends, where they would separate to some extent before discharging.

To collect the sewage to the vicinity of Rockaway Point, there would be need of a system of collecting and intercepting sewers running to all parts of the city. Staten Island would be connected by a tunnel beneath the Upper bay. Manhattan would be provided with intercepting sewers running around the water front. The sewage would pass under the East river to mains which would flow to storage reservoirs. The sewage of Brooklyn would be collected by interceptors and one trunk line would run to the Bronx and another to a central point for the sewage of Northern Queens.

To a large extent the present local sewerage systems which receive the sewage directly from the houses would be utilized, but the main drainage system would consist, for the most part, of conduits of large magnitude, some of them approaching the dimensions of rapid transit subways, the principal main sewers being five in number.

Various pumping stations would be required at one or more points on each of the five main sewers or their branches and a general pumping station would be necessary at Rockaway Inlet to pump the sewage to the outlet at sea. In the estimates of cost, it has been assumed that the maximum capacity of pumps in each station would be 50 per cent. in excess of what may be termed the average capacity and, in addition to this, a storage reserve capacity has been assumed in each case.

It has been assumed that the sewage would be stored during a period of eight hours when the tidal conditions were unfavorable to a discharge, and that the volume so stored would be sent to sea during the subsequent four hours, together with the sewage which reached the central pumping station during this latter period. It has been assumed that 50 per cent. of the average daily flow might reach the central station during the period of eight hours and to store this the reservoirs should have a capacity of 665,000,000 gallons. The reservoirs would have a net area of about 102 acres, allowing about 25 per cent. additional for walls, embankments, pumping station, etc., or say 23 acres.

A safe velocity of discharge through the tunnels would be about 6 feet per second, and the rate of discharge per 24 hours would be about 4,000,000,000 gallons; under these circumstances four tunnels of 18 feet diameter each would be required.

The point of outlet would be about three miles north of the Ambrose channel light vessel and about five miles southeast of Rockaway Point.

As far as estimates have been made, it appears that the plan of collecting the sewage of New York to a central point and discharging it to sea on outgoing currents would cost not less than $140,600,000. Of this sum, the sewers to the central pumping station would cost about $51,000,000, the outfall tunnels about $51,000,000, and the storage reservoirs about $6,650,000; other items, including engineering and contingencies, about $18,000,000, allowing 15 per cent., and land about $2,000,000.

It is possible that works somewhat similar to these may be needed for the remote future, but for the present no such extensive and costly scheme is necessary in order to remedy the existing conditions or is justified by the promise of benefits which would be conferred.

Application of the Sewage to Farm Lands

If the sewage of New York were collected to a central point to be utilized for agricultural purposes, it would be difficult to find a suitable location for the farms. It is unlikely that the people of New Jersey would consent to receive the sewage within the boundaries of that State. The land to the north of New York, in Westchester county and beyond, is hilly and unsuitable for irrigation. The only land which is located at a suitable elevation above the sea and is of sufficient extent to receive the large quantity of sewage which would have to be disposed of is on Long Island.

If the sewage were to be carried to Long Island for disposal on land, it should be collected first to a central point and there pumped to the irrigation fields. A suitable central point would be in the vicinity of Jamaica. Leading to this place would be a main drainage system, including inter ceptors, collectors and mains from the various parts of the metropolis. Large conduits would be needed to carry the sewage from the pumping station to the disposal fields. To accommodate the sewage in 1940, three conduits with a diameter of 19 feet each would be necessary.

The irrigation fields might begin in the vicinity of Amityville, a distance of about 30 miles from the New York City Hall. Any point nearer would be unsuitable for the disposal of a large quantity of sewage because of the numerous villages and other suburban settlements which exist.

About 175 square miles of land would be needed, assuming that 12,000 gallons of sewage could be utilized per acre per 24 hours. This is the highest rate of disposal which should be allowed. A tract of land lying at a suitable elevation and possessing the proper quality of soil can be found running from Amityville to Quogue, a distance of about 50 miles.

From an engineering standpoint, the idea of applying sewage to the sandy soil of Long Island is feasible. It is estimated that the cost of the works necessary would be about $153,000,000, exclusive of farm land. The purchase of this land would represent a large sum of money. Among the items of expense included in the estimate are the sewers leading to the main pumping station at Jamaica—$51,000,000; the gravity conduits from Jamaica to the farm lands—$34,500,000; the pumping stations at New York City and at the farm lands—about $13,000,000 each; and improvements on the farm lands—about $11,000,000. The engineering and contingencies, reckoned on a basis of 15 per cent. would amount to fully $20,000,000. In this estimate, as in the studies for the disposal of all New York's sewage at sea, the quantity of sewage for the year 1940 has been estimated to be 1,330,000,000 gallons per 24 hours and the population 9,000,000. The sewage would be the dry weather flow only. The estimates of cost should be understood as very rough approximations.

Those persons who have advocated the application of the sewage to farm lands have generally done so in the belief that the manurial ingredients of the sewage could in this way be utilized and a return made on the cost of getting rid of the sewage. It is commonly believed that the sewage of a great city should be regarded as a valuable asset, and that for economic as well as for sanitary reasons the useful ingredients should not be wasted.

Scientific men, sometimes of great eminence, have called attention to the wasteful habits which they have observed in the disposal of sewage, and have warmly advocated the employment of measures for recovering the nitrogen, phosphoric acid and other forms of plant food from sewage. Liebig and Ramsey, the great German and English chemists, are on record with regard to this subject and many persons are familiar with the striking statements of the novelist Victor Hugo on the same subject.

Numerous efforts have been made to utilize the manurial ingredients of sewage, but most of these efforts have been unsuccessful. The City of Paris disposes of a large part of its sewage by application to farm land, but it has been found that the area of land required and the many difficulties in properly applying the sewage to the soil make it undesirable that these works shall be extended. The increasing quantities of sewage which will be produced by the growing population of Paris will, in all likelihood, be disposed of in future by intensive processes of purification in which no effort will be made to recover the manurial ingredients. Experiments looking to this end have been conducted by the city for some years and extensive works on the intensive principle have recently been put into operation for a part of the suburbs of Paris.

Perhaps the most profitable example of sewage farms for a great city is afforded at Berlin. There the sewage is pumped from the city through long mains which extend in various directions to broad farm lands in the sandy plain surrounding the city. The sewage disposal fields are managed with characteristic German care and frugality. Every effort is made to turn the sewage to a profitable use, as well as to dispose of it without nuisance or injury to health. The conditions of soil and elevation of land are particularly favorable, and the land when purchased for the disposal of the sewage was cheap. The total area of land which it has been necessary to purchase in order to dispose of the sewage by irrigation is now so great that Berlin is regarded as one of the largest land owners in all of Germany. In Berlin, as in Paris, the application of sewage to land has not been found to be a commercially profitable undertaking and it is considered likely that intensive methods of purifying the sewage will, in course of time, be substituted for the sewage fields.

There are apparently insuperable obstacles to the application of New York's sewage to the soil of Long Island. Aside from the great cost of the works and land here mentioned, it would be necessary to eliminate villages and towns and require the right to the property of many large estates and public institutions or provide a much larger total area than that mentioned. More important still, a part of the water supply of New York might seriously be interfered with. Most of the drinking water for Brooklyn is obtained from wells on the south side of Long Island, and although it is possible that with the additional water supply now being brought to New York from the Catskill Mountains the Long Island ground waters will be given up for Brooklyn, it seems likely that public opinion will not permit the sewage of the metropolis to be disposed of on the land from beneath which such a valuable source of wholesome drinking water is obtainable. Finally, the south side of Long Island, to which the drainage would naturally have to flow, affords no suitable opportunity for the disposal of the effluent. From New York City, for a distance of 100 miles, this shore is bordered by broad, shallow, grassy bays which are extensively used for the cultivation of shellfish and as a place of recreation for people from New York and other cities. If the application of the sewage to the land were conducted in the most successful manner possible, so far as the recovery of the manurial ingredients and the destruction of harmful bacteria are concerned, the effluent from the fields would probably be so rich in plant food as to promote aquatic growths in the shallow bays to the point of nuisance.

INTENSIVE PURIFICATION OF THE SEWAGE

For disposal by intensive purification, the sewage could be brought to a central point by such a system of main drainage as has already been sufficiently described in discussing the possibility of discharging the sewage at sea or applying it to farm land. Perhaps the best place to which the sewage could be brought would be somewhere in the vicinity of Jamaica bay. Extensive areas of low-lying land at moderate cost occur in this locality and there is, perhaps, less likelihood of producing objectionable nuisance here than anywhere.

The process of purification would presumably be settlement for the removal of the larger solid ingredients and biological treatment for the oxidation of the dissolved organic matters. If the sewage were to be discharged without purification into the waters of Jamaica bay, a procedure which would be undesirable because of the shallow, grassy nature of that body of water and from the fact that large numbers of persons might be affected through the pollution of shellfish, the effluent could be disinfected so that it would be practically, if not completely, free from disease germs.

The intensive purification of sewage has come into general use in recent years. Its sole object is to dispose of those organic properties of sewage which cause offense when the sewage is discharged into water in excessive quantity or put upon land to an amount beyond the natural digestive capacity of the soil. As a general thing no effort is made to recover the nitrogen or other useful property, the end sought being the sanitary disposal of the sewage in the most expeditious and inexpensive manner possible. Many of the largest cities employ intensive methods of sewage treatment, including London, Glasgow, Birmingham, Manchester, Salford, Leeds, Sheffield, Hamburg, Frankfort, Cologne and Dresden.

The degree of purification accomplished in each case is not the same, the object in designing the works being to fit the process to the local situation in such a way that the cost will not exceed the requirements of the particular case.

Included in methods which may be employed in the intensive purification are screens, settling basins, precipitation tanks, septic tanks, hydrolytic tanks, slate beds, contact beds, percolating filters and intermittent filters. There are various types of apparatus in which these forms of treatment may be carried out, and there are sometimes several ways of operating the same apparatus.

For New York, if 1,330,000,000 gallons of sewage were to be treated on the shores of Jamaica bay, the process should be as thorough and complete as practicable or the effluent would have to be carried well out to sea. Estimates have been made of the cost of intensive treatment, assuming that disinfection would not be necessary, but that settlement in two-storied tanks followed by oxidation in sprinkling filters would be the most desirable process. The collection and treatment works would cost approximately $141,000,000. Among the principal items would be the sewers leading to the works and the works themselves, each of which items would represent not less than $50,000,000. The pumping station would cost about $12,000,000 and the outfalls not less than $5,000,000. The engineering and contingencies, reckoned on the basis of 15 per cent., would amount to about $18,000,000. This sum, in the opinion of this Commission, is a large price to pay for the results which would be accomplished.

It must be conceded that the purification of sewage by the more refined processes cannot be carried on without risk of producing objectionable conditions. Whether these conditions amount to a nuisance depends upon the extent to which the land in the vicinity of the works is occupied and the nature of this occupancy. Unpleasant odors and the presence of flies, while not seriously objectionable at a distance of several miles, would be a source of decided nuisance in the midst of a closely built-up residential quarter. The larger the works, the more extensive the nuisance which would be likely to occur. The disposal of more than a thousand million gallons of sewage per day by means of sprinkling filters or contact beds could not be accomplished on the shores of Jamaica bay or anywhere else within the limits of New York City without giving rise to conditions so objectionable as to put the idea of purifying the sewage intensively out of the question.

Partial Purification on an Island at Sea

Although it would apparently be impracticable to carry all the sewage of New York sufficiently far to sea to permit it to be discharged in crude condition and equally inadmissible to highly purify so large a volume of sewage within those sections of New York which are already thickly built up or likely to become so, a combination of ocean discharge and intensive purification should be considered. If the sewage could be relieved of a large part of its potentially harmful matter, it should be possible to discharge the effluent comparatively close to shore, and if the effluent could be discharged within a short distance of the coast line, it should be possible to build an island at not too great cost to withstand the destructive action of the sea. This combination presents certain features which require further discussion.

As to the location of an island, the situation is comparatively simple. No island now exists which could be employed for the required works. It would be necessary to build one on the extensive sandy bottom of the sea as it shelves upward to the shore and approaches the entrance to New York harbor. The sandy bottom is, according to the best information available, of permanent configuration. It would apparently be necessary only to deposit a mass of rip rap in the form of a wall and deposit rock or earth or sand within the enclosure until an island had been formed of the proper dimensions. The distance from shore should be as great as it would be practicable to go in constructing the tunnel. Detailed study will probably show that this distance should not be more than a few miles. The further the island was from shore, the greater the expense of constructing it and the greater the difficulties and cost of building the tunnel. It is probable that it would be more economical to purify the sewage to a comparatively great extent and carry on the operation comparatively near shore than to build the island at such a distance as would permit the sewage to be discharged in nearly crude condition. Three general localities appear possible as the sites for an artificial island. The one further at sea is where the Ambrose channel light vessel is situated approximately in longitude 73 degrees 50 minutes and latitude 40 degrees 28 minutes. There is here extensive shoaling due apparently to continued discharge of cellar dirt and other heavy refuse dumped from boats engaged in carrying this material from the cities in the metropolitan district. The water at mean low tide ranges from 34 to 60 feet and surrounding this point in all directions the depth is over 70 feet. To the south and east the water soon attains a depth of 100 feet. To the north and west it shoals rapidly to depths of 50 and 40 feet in the direction of Rockaway Point. The distance from the nearest land is 7 miles to Rockaway Beach. This point, which may be termed Ambrose shoal, is fully exposed to ocean storms, and if an artificial island is constructed here, it would have to be of massive and correspondingly costly construction. A second point which appears to be suitable for an island is about a mile east of the outer entrance to Ambrose channel at 40 degrees 30 minutes by 73 degrees 55 minutes. The water here is about 32 feet deep at mean low tide and the distance from shore is about 3½ miles. Deeper water lies to the south and east. The ocean storms act directly and with unabated force at this point and if an artificial island were to be constructed here, it would have to be of great strength to resist the destructive action of the waves. Considerable saving would, however, be effected over the cost of an island at Ambrose shoal because of less depth of water to be filled and less depth and length for the sewage tunnel. The amount of treatment necessary to the sewage at Ambrose shoal would be a minimum. Perhaps no treatment whatever would be required. Some treatment would be necessary if the island were constructed at the point nearer shore. Plain sedimentation would probably be sufficient at this point.

A third location for the island exists among the shallow reefs which once formed what was known as the bar across the harbor in Lower New York bay. Here the water is not over 12 feet deep in places and it would be feasible to construct an artificial island of large size at comparatively small expense. Deeper water lies in the vicinity. Tunnels which would carry the sewage from the shore would have to pass under water which would be not more than 23 feet deep at mean low tide. The distance from shore would be about 3 miles. The location would be about 40 degrees 31 minutes by 73 degrees 58 minutes. If 1,330,000,000 gallons of sewage were to be brought to this point each day, it would have to be purified to a very considerable extent.

This Commission considers that the plan of collecting all the sewage to one central point is unnecessary for the reason that other remedies costing less money, involving fewer engineering and sanitary difficulties and promising equally satisfactory results are feasible.

CHAPTER II

THE FOUR PRINCIPAL DRAINAGE DIVISIONS IN THAT PART OF THE METROPOLITAN SEWERAGE DISTRICT WHICH LIES IN NEW YORK STATE

In another part of this report a description is given of various ways in which the sewage of New York can be collected to a central point for disposal and it is there stated that it is the opinion of this Commission that works of less magnitude and cost than one great system of main drainage can be constructed to answer all the requirements of the harbor as a whole and satisfy the needs of every locality.

It is desirable here to state some of the fundamental considerations upon which the necessary works for the reasonable protection of the waters should be based, and in particular to describe the four principal drainage districts of New York City in which the many problems connected with the engineering works should be laid out.

The division of the territory into drainage areas is fundamental to the proper design of such large sewers, purification plants and outlets as are required. The boundaries of these divisions should coincide approximately with the principal natural drainage areas of the land. The sewage should be collected and treated in each of these divisions in such ways as to afford all the relief needed in the near future and the design of the works should be such as to afford a more and more complete protection as the needs of the future may demonstrate. The quantities of sewage produced, the facilities which are open in the several localities for disposing of it in a sanitary manner and considerations of cost should have due weight in making the plans. The form, location, extent, depth and volume of the tidal water passing, the uses of the water for traffic, recreation, shellfish culture, bathing and other purposes and the present and probable future sanitary and aesthetic requirements of the public should receive due attention.

For purposes of administration during the construction and maintenance of the works, it was at first thought that the division of the territory should harmonize, if possible, with the separation of the city into boroughs, but a rigid agreement with the borough boundaries was soon seen to be impracticable and unnecessary. In some cases the natural drainage of two or more boroughs was tributary to a main division of the harbor which it was desirable to protect. In other cases it would be necessary to gather sewage from two or more boroughs to one central point for disposal. Under such circumstances rigid adherence to borough lines as the boundaries for the sewerage divisions would not be possible.

In separating the territory into main sewerage divisions the chief consideration was to provide for an adequate and economical protection of the harbor water and to accomplish this object this Commission has been guided by the well-established engineering examples afforded in the successful protection of the harbors of other great cities, that is, by large intercepting sewers, usually running along the shore line to well situated central stations where the sewage can be treated for the removal of more or less of its impurities and the effluent discharged into deep, broad currents of open tidal water.

The extent to which the harbor needs protection has been regarded as of fundamental importance in these studies. The Commission has formed the opinion that it will not be necessary to keep all the sewage out of the harbor, for these waters can absorb a large amount of sewage in a harmless and inoffensive manner. This capacity should be fully utilized and the Commission has given much time to the study of the extent and way in which this can be done.

It has been considered desirable to formulate a definite series of rules or restrictions which would serve as a standard of purity or of cleanness for the water and form a serviceable guide in determining to what extent the sewage should be kept out of the harbor. Much care was used in preparing this standard. To assist in drawing it up, this Commission invited a number of prominent sanitary experts from various fields of professional activity to give their attention to certain specific questions and put their opinions in the form of written reports. A standard of cleanness proposed by this Commission in the light of the opinions of the eight experts consulted has been published in a report dated August, 1912, and is to be found in another part of this report.

Quantity of Sewage Entering New York Harbor

The eight divisions into which New York harbor has been separated for purposes of study have been described in the Commission's report of August, 1912. To these is here added a ninth, to include the sewage which is naturally tributary to the Passaic and Hackensack rivers.

In preparing Table II, the dry-weather flow of sewage discharged into each division has been assumed to be the same as the volume of the public water supplies of the areas tributary to the respective divisions. Where future quantities are considered, the sewage to be expected is in most cases based on the estimate of the authorities who are charged with the duty of providing the public water supplies. The populations for 1910 have been taken from the United States census reports; those for 1940 are based on carefully made estimates by this Commission, revised with the latest information obtainable.

TABLE II

POPULATIONS AND VOLUMES OF SEWAGE DIRECTLY TRIBUTARY TO THE SEVERAL DIVISIONS OF THE HARBOR

Division of the Harbor.	Sewage.	Year 1910.			Year 1940.		
		Sewage Mgd.*	Population.	Gals. per Capita per Day.	Sewage Mgd.*	Population.	Gals. per Capita per Day.
Harlem river	Manhattan	70	522,000		156	960,000	
	Bronx	29	275,000		97	748,000	
		99	797,000	124	253	1,708,000	148
Hudson river	Manhattan	98	726,000		238	1,470,000	
	New Jersey	34	283,000		64	470,000	
		132	1,009,000	131	302	1,940,000	156
Upper East river	Bronx	17	156,000		63	452,000	
	Queens	4	26,000		36	197,000	
		21	182,000	115	99	649,000	152
Lower East river	Manhattan	144	1,083,000		189	1,170,000	
	Queens	8	60,000		52	383,000	
	Brooklyn	94	915,000		213	1,670,000	
		264	2,058,000	120	454	3,223,000	141
Upper bay	....	64	519,000	123	118	908,000	130
Newark bay	Bayonne	1.3	18,000		7.1	51,000	
	Jersey City	0.8	6,000		1.1	8,000	
	Newark	10	67,000		18	115,000	
	Elizabeth	1	12,000		3.6	26,000	
		13	103,000	126	30	200,000	150
Kill van Kull	Bayonne	1.8	23,000		9	64,000	
	Richmond	5	27,000		14	75,000	
		7	50,000	140	23	139,000	165
Jamaica bay	Brooklyn		270,000			619,000	
	Queens		81,000			290,000	
		53	351,000	151	163	909,000	180
Passaic and Hackensack rivers	New Jersey	130	950,000	137	349	1,900,000	184
Totals	....	765	6,019,000	....	1,719	11,576,000	...

*Million gallons per 24 hours.

From Table II it will be seen that the total quantity of house sewage tributary to the harbor in the year 1910 was 765,000,000 gallons per 24 hours, and the population supplying this sewage was 6,019,000. By 1940 the population will be almost doubled and the quantity of sewage will be more than doubled. The sewage expected in 1940 in one day will be enough to fill a reservoir one square mile in area and 10 feet deep.

A glance at Table II shows that a proportionate burden of pollution is not placed upon each division. The Lower East river receives much more sewage than any other division in comparison with its size. This will be true, also, in 1940, if nothing is done to prevent it. At that time over one-fourth of the total amount of sewage produced in the metropolitan district will be directly tributary to this stream. The increase which will go to this division from Brooklyn and Queens will be about half the quantity which was produced by Manhattan in 1910.

Table III has been made from data contained in the report of this Commission, dated August, 1912. Of particular interest are the suspended organic and volatile matters.

TABLE III

Assumed Composition of the Sewage Which is Tributary to the Harbor on the Basis of 100 Gallons per Capita per 24 Hours. The Quantities Are Expressed in Parts by Weight per Million of Water.

Solid Matters	800	Nitrogenous	150
Dissolved	500	Nitrogen	15
Suspended	300	Non-Nitrogenous	250
Organic and Volatile Matters	400	Fats, etc.	50
Dissolved	200	Total Carbon	200
Suspended	200		

The Four Divisions of New York and Their Main Characteristics

Keeping in mind the considerations which have affected the separation of the territory into divisions and remembering that sewerage systems must conform closely with natural drainage areas, the method adopted by this Commission for separating the territory into main sewerage divisions may be easily comprehended. The drainage areas included within the principal ridges or watersheds have been laid down on a map and these areas have been formed into four large groups, depending upon the part of the harbor into which the drainage naturally discharged (see Frontispiece). Hereafter, these groups will be called by this Commission divisions and the separate drainage areas within them, for which a system of main drainage has been designed or considered as properly tributary to a single outlet, will be termed subdivisions. The four main sewerage divisions will be designated according to the parts of the harbor to which they are tributary. As far as possible, the subdivisions will receive names which will sufficiently indicate their general location. In one of the divisions, the subdivisions are so numerous and their locations so impossible to indicate by distinguishing names that numbers arranged in consecutive order will be used.

The territory on Manhattan Island and in Brooklyn which naturally drains into the Lower East and Lower Hudson rivers and Upper New York bay constitutes the Lower East River, Hudson and Bay Division.

The areas in the Boroughs of Queens and the Bronx which naturally drain into the Upper East river, and those parts of the Boroughs of Manhattan and the Bronx which naturally drain into the Harlem river constitute the Upper East River and Harlem Division.

The territory whose drainage flows or can readily be made to flow into Jamaica bay is called the Jamaica Bay Division.

The territory in the Borough of Richmond, or, as it is more generally termed, Staten Island, constitutes the Richmond Division.

These four divisions are markedly dissimilar in topography, density of population and in location with respect to the ocean and to large volumes of swiftly-running tidal water, yet the main drainage and sewage disposal problems are not greatly dissimilar.

The Selection of Central Points for Disposal

Having tentatively settled upon the main divisions, the selection of the central points to which the sewage should be collected for treatment and disposal became a matter of principal importance. Upon the choice of these points depends not only the cost of collecting the sewage, but the method of treating it and the facility with which the effluent can be disposed of after treatment.

It was considered by the Commission that as far as practicable, the collection point should be near the ocean or Long Island sound or close to deep tidal channels. Points of outlet for untreated sewage, if any sewage was to be discharged in crude condition, should never be situated in shallow, stagnant, land-locked or remote parts of the harbor. Favorable conditions for a prompt dispersion and digestion of the sewage matters should be sought. Where facilities were lacking for the disposal of the sewage through dilution by large volumes of freely flowing tidal water, compensation for this lack should be made in the degree of treatment given to the sewage for the removal of its organic ingredients before the discharge.

It was considered desirable to make the number of central points as small as practicable in order to simplify the problem of administration and to facilitate the ultimate disposal of the sewage, due attention being given to the probability that pumping would have to be employed to some extent and to the fact that for purposes of economy of operation the works should be as compact and concentrated as is consistent with due regard to the first cost.

The exact degree of purification required for the sewage could not be stated when this method of designing the works was decided upon, but it was the opinion of the Commission that elaborate processes and those which required much land, extensive apparatus, patents and untried or experimental features should be avoided as far as practicable. As between large first cost and low running expenses, or small first cost and high maintenance charges, the Commission favored the former as likely to lead to more satisfactory results, since the expenditure represented by the large investment would be made up chiefly of interest charges which could be reckoned with in a definite manner and so free from the uncertainties of such elements of expense as are involved where large quantities of supplies and labor are concerned. So far as methods of purifying the sewage are concerned, the object was to make good use of the absorptive capacity of the harbor waters and purify the sewage no more completely than was necessary in order to satisfy a reasonable standard of cleanness. By good use is here meant such use as would do no material harm to the public health and welfare either through the production of disease or nuisance. To a large extent, screens, grit chambers and similar methods of so-called preliminary treatment should be employed. Only in exceptional cases would the utmost degree of purification be required.

Definiteness of the Plans and Estimates

In making the plans and estimates of cost of the main drainage works for the various divisions, it has not been practicable to arrange the final details. The exact locations of the lines and their precise grades and sizes could not be fixed without making surveys and borings on an extensive scale. At the same time, it has been considered desirable that the Commission's studies should be as definite as practicable and to this end an effort has been made to utilize the existing information concerning the topography, population to be served and other conditions. Investigations have consequently been undertaken and efforts made to obtain from the local sewer bureaus, topographical bureaus and elsewhere such data as were available and the plans here proposed are largely based upon a consideration of the facts so obtained.

The plans proposed in this report are to be regarded as the outcome of the Commission's studies based on the outlook in the year 1914 for the municipal development of the region under consideration, on the standard of cleanness which seems necessary and sufficient at this time and on the existing state of the art of sewage disposal. All the work planned will not be needed in the immediate future, but it is regarded as essential that such main drainage works as are undertaken should conform to these general plans and be made part of the comprehensive scheme. The possibility that a more complete system of protecting the waters than that outlined here may be needed in the distant future has been kept in mind in preparing the plans. The works have been intended to be extensible in character: that part which should be undertaken immediately may be regarded as the beginning of a system which will eventually be much more complete. As greater protection is needed, it can be secured by extending the works without undue sacrifice of any part of the completed structures.

In designing the main drainage works, careful account has been taken of the character and location of the existing sewers. Most of the sewers already constructed by the city were built to accommodate house, factory and storm water drainage. Where no sewers have been built or have been designed and a separate system seems more suitable, it will be assumed that a separate system will be constructed and provisions have been made in the plans for main drainage for the sewage to be collected in this way.

In no instance has this Commission concerned itself with the design of the sewers which will now or in future run through the streets to collect the sewage directly from the houses. The design of such sewers and their maintenance is regarded as the proper work of the local sewer bureaus. The main drainage works may be contrasted with the local sewers as offering a proper outlet for the latter: The main sewers will take the sewage wherever the local systems have collected it. It is the function of the main drainage system to protect the waters into which the local sewers would ordinarily discharge and in doing so they must intercept the sewage and carry it to centrally located points where it may be properly disposed of. Most of the sewers which this Commission proposes are termed interceptors, since they will run along the shore line and intercept the sewage which otherwise would flow from the local sewers to the water; in some cases the term collector will be used to designate a large sewer which will gather the sewage from inland areas and carry it to proper points for disposal. In a few cases inverted siphons will be required to convey the sewage across some arm of the harbor. The term force main is used to indicate a line through which the sewage is pumped and the term main sewer is used to indicate the line leading from an important point of collection to the outlet.

Table IV contains various unit prices used in the estimates.

TABLE IV

Unit Prices Used in Estimating Cost of Main Drainage Works

Brick-Work, per cubic yard	$14.00
Cast Iron Pipe, per ton	26.00
Concrete—Plain, per cubic yard	8.00 to $10.00
" Reinforced, per cubic yard	10.00 " 12.00
" In Baffles, etc., per cubic yard	12.00 " 15.00
Dredging, per cubic yard	.19 " .25
Excavation—Depending on Conditions.	
Filling behind Bulkheads, per cubic yard	.50
Hauling, per ton mile	1.00
Lumber in Foundations, per M, b.m	30.00 to $35.00
Piling, per lin. foot	.30
Repaving, per square yard	.50 to $ 2.00
Rip Rap, per cubic yard	.50 " 1.80
Steel for Reinforcing, per lb	.02½
Tunnel Excavation, per cubic yard	6.00 to $ 8.00
Same when under air pressure, per cubic yard	10.00 " 12.00

A BRIEF DESCRIPTION OF THE FOUR DIVISIONS.

Lower East River, Hudson and Bay Division.

The greatest part of the most densely settled portion of New York City is included in the Lower East River, Hudson and Bay Division. This includes all of the Borough of Manhattan except that portion at the northeastern end which naturally drains into the Harlem river; all of the Borough of Brooklyn except that part which naturally drains into Jamaica bay, and the eastern end of Gravesend bay; and that part of the Borough of Queens which naturally drains into the East river south of Lawrence Point near Hell Gate. To the southeast lies the Jamaica Bay Division, to the northeast the Upper East River and Harlem Division and to the southwest the Richmond Division.

Practically this whole division is now thoroughly sewered on the combined plan. Sewers discharge near the level of low tide and, except in the Borough of Manhattan, usually at the bulkhead or shore line. The sewers of Manhattan, for the most part, are carried out nearly to the outer ends of the piers which project perpendicularly from the shores at frequent intervals. There are about 200 sewer outlets in this division. Nearly all the extensive shore line is low and flat. The average tidal range is 4.4 feet.

The waters into which the crude sewage of this division is now discharged are those arms of the harbor from which the division takes its name. During the dry seasons of the year practically the same water circulates back and forth in the bay, East river and Hudson river, which together may be likened to the stem and arms of the capital letter Y. After continued heavy rains, the Hudson discharges a heavy flow of water from the land and this discharge of upland water produces effects which are visible in the Lower East river and Upper bay. This change comes on suddenly and causes the water to appear turbid and brownish in color. Normally the water is of an olive green hue and is slightly turbid.

The Hudson river is a broad, deep waterway capable of accommodating large seagoing vessels. Upper New York bay, while deep in the main channels, contains extensive shoals on its east and west sides. The shallow flats on the west side underlie about one-third of the entire water surface and are covered with from 2 to 10 feet at low tide. The Lower East river is narrower and swifter than the Hudson, but of about the same depth. The East river is in reality a strait which joins Upper New York bay with Long Island sound.

The construction of main drainage works in this division are difficult by reason of the large quantities of sewage to be dealt with, the slight elevation of the shores above tide water, the completeness with which the territory is built up, the large amount of vehicular traffic and the great extent to which structures have already been built beneath the surface of the ground.

Upper East River and Harlem Division.

The Upper East River and Harlem Division includes nearly the whole of the Borough of the Bronx, that part of Manhattan Island which naturally drains to the Harlem river and that part of the Borough of Queens whose natural drainage flows to the East river east of Lawrence Point near Hell Gate. The topography and municipal development of this division is various in the extreme. The elevation of land in the western part of the Bronx is high, the Harlem river flowing for part of its way between steep banks. To the east, steep, narrow valleys run between parallel ridges in a northerly and southerly direction, the land gradually becoming more uniform in contour eastwardly. The topography of that part of this division which lies in Queens is notable for its sloping land which is situated at a considerable elevation and for its extensive low-lying meadows opening into the East river. Both sides of the Upper East river are characterized by elevated promontories and deeply placed bays. A natural channel suitable for vessels of not more than 24 feet draft runs between the headlands throughout this part of the river. The rise and fall of tide in the Upper East river is comparatively great for the metropolitan territory, amounting to about 7.5 feet at Whitestone.

The Harlem river joins the Hudson with the East river and forms the northern boundary of Manhattan. It is narrow and shallow compared with the other main parts of the harbor, its present use being chiefly for light draft shipping.

Municipal conditions vary widely in this division. There is an area of several square miles in the southwestern part of the Bronx which is almost as densely settled as any part of the City of New York. There are parts of Queens which possess every semblance of rural remoteness. Rural and semi-rural conditions exist in parts of this division. Isolated towns with large residence populations are growing and will doubtless ultimately converge, while new centers are constantly being established through the efforts of enterprising real estate operators. In 1910 the population of this division was about 1,103,000. By 1940 it is expected that the population will be 2,400,000.

Jamaica Bay Division.

The Jamaica Bay Division faces the Atlantic ocean and is so situated that it is in little danger of being affected by the drainage of the rest of the city. This division is bounded by a ridge of land which begins at Bensonhurst, Gravesend bay, runs in a general northeasterly direction to the eastern boundary of New York City and proceeds beyond that boundary to a point just west of Roslyn, where it bends south and extends to Lynbrook and thence follows the height of land along the Rockaway peninsula to the city line and the ocean. About 103 square miles are included in this division; of this, about 76 square miles are land and 27 square miles water or low-lying marshy islands. Jamaica bay is shallow except in its southwestern part, where a deep channel enters from the ocean and, dividing into numerous branches, flows among the islands. The refreshing action which the tide produces upon the bay is large, for the bay is so shallow that much of its water leaves it at each falling tide and is replaced by water from the sea as the tide rises. The large water surface favors the absorption of oxygen from the atmosphere and the shallow depth helps a thorough mixture of the waters, two conditions which give the bay considerable advantage in the harmless and inoffensive assimilation of sewage matters. On the other hand, there are large areas of bottom exposed at low tide which would become offensive if polluted by sewage. In the extensive shallow parts of the bay there are dense growths of vegetable matter which, decomposing, sometimes make a considerable demand upon the dissolved oxygen in the water. Probably four-fifths of the bottom of Jamaica bay is covered with black mud in which vegetable and animal organisms in great variety exist.

Clams, both the soft shell, Mya arenaria, and the hard shell, Venus mercenariam, grow luxuriantly and are taken from the waters in large numbers. Soft shell clams are in places taken under circumstances which lead to the opinion that they are frequently polluted.

Oysters are planted extensively on the harbor bottom near the sides of the main channels in the southern part of the bay. The oysters grow well and command good prices in the market. Many are eaten raw, although the typical oysters originally cultivated in this vicinity, formerly known as Rockaways, were large and generally used for cooking.

Fish do not enter Jamaica bay from the ocean except in small numbers and at certain seasons of year, although there is usually excellent fishing in the ocean a few miles outside of the inlet. A numerous fleet of small fishing boats with headquarters inside the bay is constantly engaged in ocean angling.

Much of the territory in the Jamaica bay division is in a state of transition from open, rural country to built-up city conditions. Extensive sections along the southern shore possess the characteristics of a permanent development.

It has been proposed by the City of New York and National Government to construct extensive engineering works to convert Jamaica bay into a safe and convenient harbor for ocean-going vessels and if this is done, as now appears likely, the natural characteristics of the bay will, in large part, give place to deeper, straighter, wider channels, canals and bulkheaded shores. Sewage now enters the bay from a few large sewers on the northern and western shores and from many small outlets on the south. The large sewers are mostly connected with sewage disposal works designed to operate on the principle of chemical precipitation. These works are all inefficient and have repeatedly been criticised adversely by and for the Bureau of Sewers of the boroughs in which they are situated.

Richmond Division.

The Richmond Division includes the whole of Staten Island. It has an area of about 57 square miles, of which about one-sixth is marsh land.

Staten Island is, in part, rough, high and hilly and, in part, low-lying and flat. The high parts of the island lie along a broad ridge which extends in a northeasterly direction at a distance of from two to four miles from the shores of Lower New York bay.

The waters of Lower New York bay are shallow for a long distance seaward from the Staten Island shore. On this account and for the reason that the shore is comparatively inaccessible by land transportation and because of the exposure of this part of the island to the open sea, it seems likely that the commercial development of this water front will long remain dormant. The south shore is now occupied largely by summer residents and by permanent settlers who live in small villages near the foot of the hills. There are several extensively patronized bathing beaches on the south shore of Staten Island. The west side of the island, bordered by the Arthur Kill, has been developed to some extent for manufacturing.

The principal residence and business parts of the Richmond Division lie at the north end of the island. Here numerous large towns are situated, each fronting on Upper New York bay or the Kill van Kull and bordered on the other sides by other towns or the open country. The business done is chiefly manufacturing and maritime and is carried on close to the water's edge. In the year 1910 the population was about 90,000. The towns of Staten Island are partly sewered. There are about 30 main outlets from which the sewage is discharged without treatment.

CHAPTER III

THE UPPER EAST RIVER AND HARLEM DIVISION

TOPOGRAPHICAL FEATURES OF THE DIVISION

The Harlem river and the Upper East river determine the principal topographical features of this division. The Harlem river runs through a narrow valley with shores which are in part densely populated, or are certain to become so at no distant day. The shores of the Harlem are nearly parallel, the stream resembling, in some respects, and being actually in part, a canal. The water is already so overburdened with sewage that no system of diffusion or other partial remedy is capable of sufficiently improving it. There is not room on the drainage area of the Harlem for purification works capable of sufficiently improving the sewage to permit of its discharge into these waters, and consequently the sewage must be taken elsewhere.

The shore lines on both sides of the Upper East river are markedly irregular; the water surface being characterized by a series of large, shallow bays along the whole length, separated by long, narrow points of land.

The water in the main channel which flows through the Upper East river is not now overburdened with sewage, nor is it likely soon to become so. It has a large capacity for assimilating sewage, provided the sewage is properly treated and then discharged directly at the bottom of the tidal stream.

The parts of this territory which present difficulties to main drainage are chiefly flat, low-lying valleys which extend long distances inland from the shallow bays of the river.

Except in the closely built-up part of this division, which is, or will be, tributary to the Harlem river, the population in the territory included in this report is chiefly of a semi-rural residential character, located in numerous growing villages not largely devoted to manufacturing. The future of this division seems to lie in its more complete occupation for residential purposes. The configuration of the shore, the shallowness of the water, except in the main channels, and the distance from the metropolitan centers of commercial activity are opposed to the extensive development of this section for the uses of manufacturing and transportation.

Bathing beaches, camps and other provisions for recreation at moderate expense during the summer months are now more or less numerous and seem destined to increase in popularity unless the pollution of the harbor water should become so great as to be too objectionable.

Formerly shell-fish of excellent quality were gathered in large number in the Upper East river, and even at the present time hard-shelled clams are dredged near where the river joins Long Island Sound. Except for small boats, yachting, which was, and is, enjoyed by many persons in the Upper East river, has for the most part sought Long Island Sound for the clearer water, lesser tidal currents and greater freedom from traffic which there prevail.

SEPARATION OF THE DIVISION INTO FIVE PARTS FOR MAIN DRAINAGE PURPOSES

To facilitate the sewerage and drainage of the Upper East river and Harlem division the entire territory has been separated in this report into five subdivisions.

In each subdivision the sewage is to be collected to a central point for treatment and discharge. The boundaries of the five subdivisions follow:

1. *The Harlem Subdivision* comprises the land in the Borough of Manhattan, north of 82d street, naturally draining to the Harlem river, and that part of the Borough of the Bronx lying west of the Bronx river, except a narrow strip draining to the Hudson river.

2. *The Eastern Bronx Subdivision* comprises that part of the Borough of the Bronx which lies east of the Bronx river. Westchester, Unionport and Van Nest are situated within this area.

3. *The Northwestern Queens Subdivision* comprises the northwestern part of the Borough of Queens, draining mostly to Bowery bay and to the westerly shore of Flushing bay, and includes North Beach, Woodside, Steinway and a part of Corona.

4. *The Corona-Flushing Subdivision* comprises that portion of the Borough of Queens tributary to the East river, which extends from the southeastern boundary of subdivision 3 southerly to the main divide of Long Island and easterly to a line running through Whitestone and Ingleside. Most of this area lies in the Flushing creek drainage basin. Winfield, Elmhurst, Corona, Flushing and College Point and parts of Whitestone are situated within its limits.

5. *The Northeastern Queens Subdivision* comprises that part of the Borough of Queens, tributary to the East river and Little Neck bay, which lies east of the limits of subdivision 4. Douglaston, Bayside and the greater part of Whitestone are included in this area.

POINTS FOR CONCENTRATION AND DISCHARGE OF THE SEWAGE

The sewage will be collected to as many points as there are subdivisions.

The sewage of the Harlem subdivision is to be carried to Wards Island, where it is to be treated and the effluent discharged into the swift currents of Hell Gate.

The sewage of the Eastern Bronx subdivision will be collected near Clason Point, where, after treatment, it will be discharged into the deep water of the Upper East river.

The sewage of the Northwestern Queens subdivision will be carried to a point in the neighborhood of Hell Gate and there discharged.

The sewage of the Corona-Flushing subdivision will be brought to Tallman Island, where treatment works can be located. The sewage will be discharged into the East river under conditions favorable for diffusion.

The sewage of the Northeastern Queens subdivision will be carried to Cryders Point, just west of Little bay and opposite Throgs Neck. There the sewage can be discharged into deep water at the extreme east end of the East river.

METHODS OF TREATMENT

The methods of treatment proposed have all been found to give good results elsewhere. They are among the least offensive and most economical methods and are capable of producing effluents which, under suitable conditions, may safely be discharged into the harbor. (See Part IV, Chapter II, "Sewage Disposal," page 421.)

With increasing populations, it is probable that the time will arrive when a more thorough treatment will be desirable and this contingency has been borne in mind in the preparation of the plans proposed. The rate of development of the several subdivisions cannot be predicted with certainty, but if the plans submitted are carried out they will afford all the protection the harbor will require for the next fifty years and can thereafter be adapted to such changed conditions as may occur without material alteration.

Methods of Treatment Proposed. After a careful study of the question of the form of treatment required for the sewage of the Upper East river and Harlem division, due regard being had to the needs of each of the five outlets, the conclusion has been reached that fine screening or coarse screening and sedimentation will, for some years, give an effluent of satisfactory character for discharge into the water of the East river.

Where sedimentation tanks are to be used, coarse screens will be employed to protect the pumping machinery and to keep large floating matters from causing trouble in the tanks and from passing out through the outfall.

In all cases grit chambers will be placed on the lines of the main trunk sewers at or near the treatment works. In these chambers the sewage will be given a settling period of from one to two minutes, the velocity being reduced sufficiently to allow the heavy mineral detritus borne by the sewage to be deposited, but not enough to permit much organic matter to settle.

The grit chambers will afford protection to the pumps and will keep the proposed long and deep outfall pipes clear of gritty deposits wherever sedimentation tanks are not used. Where sedimentation tanks are planned, the grit chambers will first rid the sewage of suspended matter of a kind which would cause trouble and be difficult to handle if allowed to settle in the tanks. Grit chambers are especially useful where combined sewers are intercepted or form a part of the collecting system, as will largely be the case with the main drainage systems as here proposed for New York City.

The treatment works at Wards Island, Clason Point and Tallman Island, for the Harlem, Eastern Bronx and Corona-Flushing subdivisions, respectively, should consist of grit chambers, coarse screens and settling tanks. Fine screens and grit chambers at the foot of Winthrop avenue, Long Island City, will suffice for the treatment of the sewage for the Northwestern Queens subdivision; the sewage from the Northeastern Queens subdivision should be passed through grit chambers and fine screens at Cryders Point, Beechurst.

If it were deemed necessary to purify the sewage from the Harlem subdivision to a greater extent than would be done by sedimentation or chemical precipitation, it is doubtful if its further purification could be undertaken either at Wards Island or at any other place in the vicinity. The area of land required for percolating filters, to treat the large volume of sewage which is to be brought to Wards Island, would require more land than is available, and the odors which might be produced by their use would be objectionable in this location. Contact beds might be employed with less objection, but it is doubtful if sufficient suitable land would be available for this purpose after a few decades.

The amount of sewage to be discharged from Queens into the East river at Winthrop avenue, although large in the distant future, will, for many years, be considerably less than the quantity brought to Tallman Island. It will never be more than a small proportion of the amount to be discharged into the river from the Wards Island sedimentation plant, only a few hundred feet distant from Winthrop avenue. In view of this fact screening is the only form of treatment deemed necessary for the sewage of the Northwestern Queens subdivision. If a more thorough treatment be needed in the future, when the volume of sewage becomes greater, it will be possible to carry the sewage by means of a tunnel under the East river to the disposal works at Wards Island; or the necessary land for a pumping station and settling tanks may be procured in the Borough of Queens.

The amount of sewage to be discharged at Cryders Point probably will always be comparatively small and the opportunity for its diffusion and digestion in the waters of the East river is favorable; therefore screening is the only treatment required for the sewage of the Northeastern Queens subdivision.

SITES FOR TREATMENT WORKS

Harlem Subdivision. After considering many projects for the collection and disposal of the sewage of this subdivision it becomes evident that it would be uneconomical to take the sewage further from Hell Gate, provided a suitable site for treatment works could be found in that vicinity.

For a time it seemed likely that Rikers Island might offer every necessary facility for the disposal of the sewage, not only of the Harlem, but of most of the other subdivisions. The area of Rikers Island is large enough for any works which might be needed, the situation is remote from inhabited shores and the island, as yet but little occupied, already belongs to the City.

Upon investigation Rikers Island was found to be unsuitable as a site for sewage disposal works. Composed of uncompacted refuse from New York City, the stability of the island is too uncertain to warrant the construction of the extensive engineering works required, and large sums of money would have to be spent for grading in order to save the excessive cost of pumping the large volume of sewage to the present level of the island.

The island known as Sunken Meadow was examined, but was found to require too much improvement to warrant its use as a location for sewage disposal works.

A better and a more satisfactory location for the works required lies at the northeast corner of Wards Island. This island is more favorably located than Rikers Island in respect to the economical collection of the sewage, and the land at the proposed site is low, firm and of sufficient extent for such works as will be required. The island belongs to the City of New York and is partly occupied by public institutions. No injury would be done by employing the corner selected for treatment works. Deep water lies close to the island; the shore is smooth and the currents are swift. The opportunities for an immediate diffusion of the sewage in the water are perhaps better at this place than at any other point in the whole metropolitan district, owing to the mixing action of the currents. (See Fig. 1.)

Eastern Bronx Subdivision. Two large areas of marsh land, southwest and southeast of Unionport, were at first considered as sites for sewage disposal works, each being of ample size, but both situated far from deep water. A more favorable site for the location of such disposal works as will be needed for this subdivision exists near Clason Point, where the ground is low and firm, and the deep and swift currents of the main channel of the Upper East river pass near the shore. A large part of the sewage from this subdivision will be brought to Clason Point by the drainage system now under construction, and the remainder can be collected at low cost.

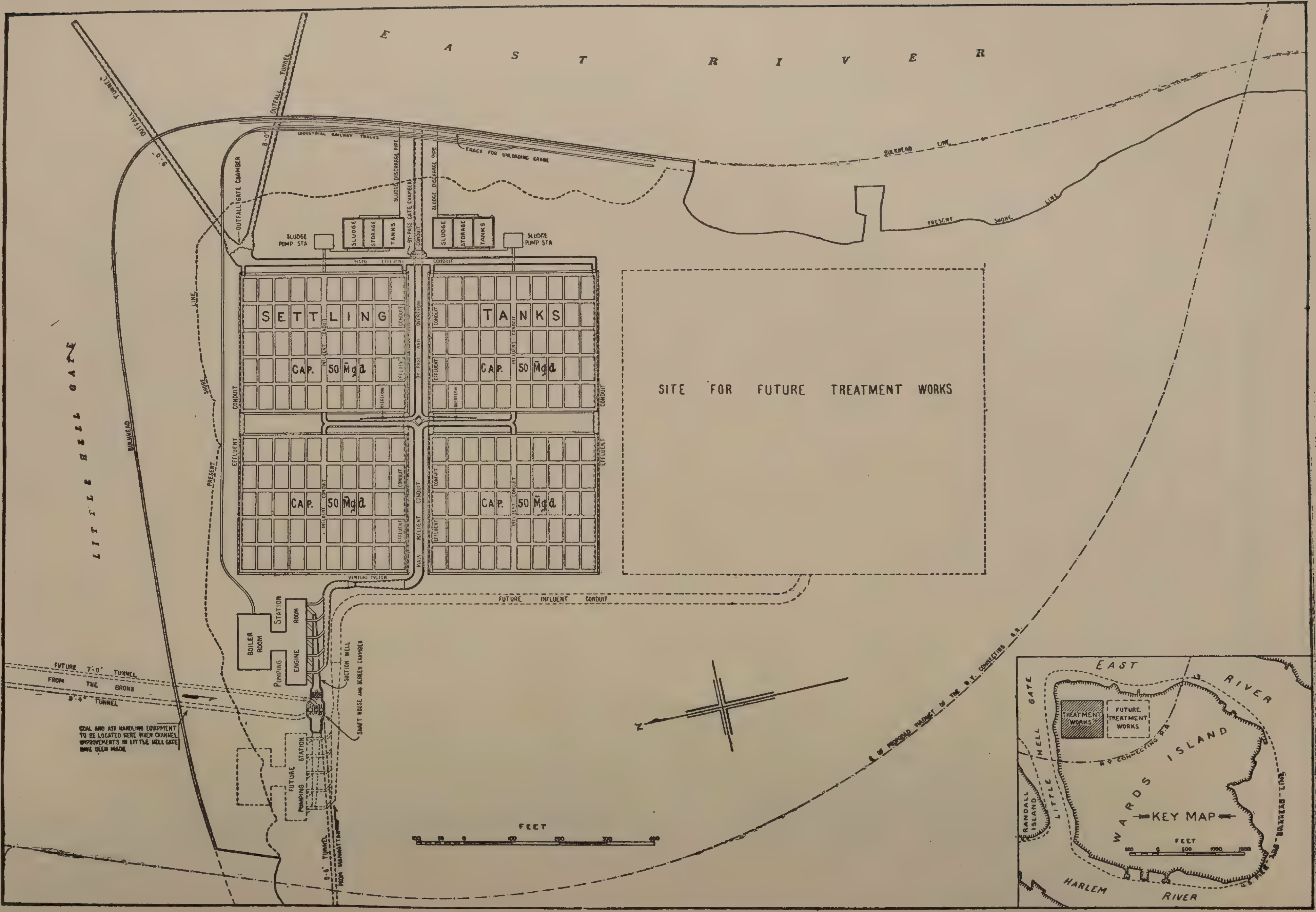


FIG. 1. Wards Island Treatment Works

Northwestern Queens Subdivision. Most of the land in the Northwestern Queens subdivision drains naturally to Flushing and Bowery bays, but owing to the shallow water and absence of currents capable of mixing with the sewage and carrying it away, there is no point in either bay where large quantities of treated sewage should be discharged. The nearest suitable point for the discharge of the sewage, after the removal of the suspended matter, is Hell Gate, near the foot of Winthrop avenue, and directly opposite the proposed Wards Island treatment works. The volume of sewage to reach this place probably will be small for many years, and such land as is needed for the simple treatment required can be procured without great difficulty or expense.

Corona-Flushing Subdivision. A large proportion of the sewage of the Corona-Flushing subdivision can easily be concentrated near the mouth of Flushing creek and the rest can be collected by a sewer running from that point to Tallman Island, where treatment works should be located.

Tallman Island is the nearest point to the mouth of Flushing creek at which treatment works, of a kind requiring the discharge of the effluent into deep water and swift currents, can satisfactorily be placed. Both land and water conditions are suitable at this point for the location of disposal works and the discharge of the effluent. The site is practically devoid of improvement and little or no injury will be caused to future development by such works as are proposed. Deep water exists at a short distance from shore, and the volume and character of water flowing past this point are favorable for the digestion of a large quantity of sewage.

The comparative ease with which the sewage from that part of the Flushing creek subdivision which lies west of the creek can be united with that from the neighborhood of Flushing and brought to Tallman Island, makes it desirable that such disposition of the sewage should be made. The sewage should not be carried to Hell Gate, for this would be more expensive and increase the burden which the water of the East river has to bear near the densely populated districts of the city.

Northeastern Queens Subdivision. The only practicable place for the discharge of the sewage of the Northeastern Queens subdivision, unless intensive treatment be employed, is the East river, between Whitestone Point and Cryders Point. The latter is the more suitable place both for the collection and the discharge of the sewage. The East river offers better opportunities for the reception of sewage off Cryders Point than it offers at Tallman Island or Clason Point. As the amount of sewage will probably be comparatively small, for at least a great many years, and the conditions for the digestion of the discharged sewage by the water are favorable, fine screening is the only treatment deemed necessary at this point. There should be no objection to the presence of a screening plant, provided the appearance of the building conforms with the surrounding development.

Instead of carrying the sewage of Bayside and Douglaston to Cryders Point, as is here proposed, it is possible to treat it on percolating filters which can be built on the marshes near Alley creek, but as these might be objectionable to the residents of the neighborhood, the plan is not considered advisable.

Outlets

Location and Depth. The sewage will be discharged in every case at a distance from the shore, the position of the outfall depending upon the nearest point at which water of suitable depth can be found. It is proposed always to have the sewage discharged at depths of from 30 to 50 feet, and in such manner as to give a favorable opportunity for its admixture with the water of the river. In order to facilitate diffusion, it will be desirable to discharge the sewage from each point at more than one outlet.

Systems of Main Drainage

Character of Sewers Proposed. The main collecting and intercepting sewers, as planned by the Commission for the Harlem, Eastern Bronx and Northwestern Queens subdivisions, will carry only the dry-weather flow of the contributing combined sewers, already built or to be built, in these districts. They are not designed to carry any portion of the storm flow. Overflows from these main dry-weather sewers will allow the storm-water to pass directly to the watercourses. The Commission does not believe that, in this district at least, the advantage gained by the treatment of the storm-water, at the works proposed, would warrant the extra expense involved in that procedure.

The main collecting and intercepting sewers, planned by the Commission for the Corona-Flushing and Northeastern Queens subdivisions, will carry only house sewage. In these areas it is especially desirable that all new sewers be built on the separate system. Throughout this territory few sewers of any kind have as yet been built. Practically the only combined sewers are in the villages of Flushing, Ingleside, College Point and Whitestone. The Commission's plans and estimates for main drainage systems in those two subdivisions have been made so as to utilize the existing sewers as far as practicable, and on the assumption that the dry-weather flow from the existing combined sewers would be intercepted, but that all sewers hereafter built tributary to these systems would carry only house sewage.

Relative Merits of Separate and Combined Sewers. Although this Commission is aware that the Board of Estimate and Apportionment of the City has approved preliminary drainage plans prepared by the Sewer Bureau of Queens Borough for a large portion of the Corona-Flushing subdivision, and that these plans call for combined sewers, except in the low lands where the street grades to be established make combined sewers impracticable, discharging into Bowery bay all the sewage originating west of Flushing creek, the Commission believes it to be desirable to provide more protection than these plans afford for keeping the waters free from sewage.

In the judgment of the Commission, the character of the territory and of the neighboring waters make separate, instead of combined, sewers generally advisable for the Corona-Flushing and Northeastern Queens subdivisions. Although the growth of population in many parts of this large area has been rapid, and with the extension and betterment of transit facilities is likely to be still more rapid in future, the total population at present is relatively small, and most of it is gathered into a number of more or less isolated residential communities. Large areas of unoccupied land exist. Notwithstanding the probable increase in population, the several communities may be expected to preserve their separate identities for many years. In these villages there probably will be only comparatively few parts which, in the near future, will support a dense population. Only small portions of the territory will need complete systems of drains for the removal of storm water. If the house sewage is removed by means of separate sewers, these can be of small size in comparison with those that would be necessary in case storm water were also to be provided for in the same system, whereas the surface water may, in many cases, be discharged into near-by watercourses, such as Flushing creek, without harmful consequences. Separate sewers can thus be made to save for the present the cost of constructing the large and long storm-water drains that will be necessary when the land around these creeks is fully developed. The construction of some of these long main drains can be undertaken gradually, as the need for them becomes evident through the development of the territory.

Practically all the unsewered communities in the Corona-Flushing subdivision are in need of sewers for the removal of household wastes. But if the house sewage from these comparatively small and isolated centers of population were to be collected and carried away in combined sewers large enough to take care of the storm-water drainage of the districts when they shall have become densely built up in the future, not only will the present per capita cost of construction be unnecessarily high, but also the small dry-weather flow in the large sewers will cause deposits to form on their bottoms, give rise to septic conditions and make a high cost for maintenance.

It would be inadvisable to recommend the installation of separate sewers in the

Harlem subdivision, as the population is practically all served at present by combined sewers, and future extensions of the same character have been planned to such an extent as to make a recommendation to this effect unwise.

In the Eastern Bronx subdivision, also, the installation of separate sewers would not be warranted, as much of the drainage system is already under construction, and comparatively little additional work is necessary in order to bring all the sewage of the district to Clason Point.

Although the separate system would be well adapted to such a development of the land as may be expected in the Northwestern Queens subdivision for many years, and would also serve better to protect Bowery bay from pollution during periods of storm, certain considerations make the separate system inadvisable in this territory. The treatment which is projected for the sewage in the near future is passage through grit chambers and screens. At some future time many parts of this territory are likely to be occupied by a rather dense population. Moreover, preliminary plans, contemplating the installation of combined sewers, have already been made by the Bureau of Sewers of the Borough of Queens and approved by the Board of Estimate and Apportionment.

Collecting Sewers for the Harlem Subdivision. The sewage of the Harlem subdivision will be collected at Wards Island by means of intercepting sewers which will follow both banks of the Harlem river and the north shore of the Upper East river west of the Bronx river, and connect with Wards Island by means of tunnels.

The sewage of that portion of Manhattan which drains to the Harlem river between 82d street and 162d street will be collected at a point in Thomas Jefferson Park just south of the corner of Pleasant avenue and 114th street. The south intercepting sewer will run from 86th street and East End avenue northerly to its junction with the north intercepting sewer in Thomas Jefferson Park. In this park, near the waterfront, the sewage from both of the interceptors will be passed through grit chambers and coarse screens, and will then be carried to Wards Island by means of a deep tunnel bored through solid rock.

The sewage of all that portion of the Bronx which drains to the Harlem river and the Bronx Kills will be collected by an intercepting sewer starting at 192d street and following as closely as practicable the easterly shore of the Harlem river at the corner of 132d street and Willow avenue. The dry-weather flow from Marble Hill and the territory around Spuyten Duyvil will be brought by gravity into the existing Broadway sewer, while that from the low land west of Kingsbridge will have to be pumped into the same sewer, which is to be intercepted at 192d street.

The intercepting sewer along the Bronx shore of the Harlem river will receive also the dry-weather flow from those areas in Manhattan north of 162d street which drain to the Harlem river, with the exception of the sewage from a small district at the extreme northern end of the island which can be better served by having its dry-weather flow pumped into a sewer at the corner of Seaman avenue and Hawthorne street, from which it would find its final outlet in the Hudson river at the foot of Dyckman street. The sewage which is to be carried from Manhattan to the Bronx interceptor will be collected at 172d street and 201st street by short intercepting sewers, passed through grit chambers and coarse screens and siphoned under the Harlem river.

That portion of the Bronx west of the Bronx river which drains to the Upper East river will have its dry-weather sewage flow collected by an intercepting sewer running from the vicinity of the Farragut street sewer outlet at Hunts Point to the corner of 132d street and Willow avenue.

At 132d street and Willow avenue the sewage from the two Bronx intercepting sewers will be passed through grit chambers and coarse screens and then carried to Wards Island by means of two deep tunnels of the same character as the one bringing the sewage from Manhattan to that place. It will be necessary to build only one of these tunnels in the near future.

As most of the area included in the Harlem subdivision is either closely built up or is rapidly increasing in population, the collecting sewers have been designed by the Commission to take care of the dry-weather flow that may ultimately be expected. The topography and other conditions are such as to make adequate relief sewers expensive and difficult to construct.

Allowance in the estimates has been made for placing automatic regulators at the points in connection with the combined sewers, so as to control the flow into the interceptor from each sewer during period of storm. Allowance has also been made for the cost of such lateral sewers as will be necessary to bring to the main intercepting sewers the dry-weather flow from the outlets of the combined sewers. Most of the combined sewers are at such elevations that tide-gates will be required so as to prevent harbor water from entering the intercepting sewers; and tide-gates have been taken into account in estimating the cost of the project.

A pumping station will be located on Wards Island for the purpose of pumping all the sewage of the Harlem subdivision into the treatment tanks to be installed there. Final discharge of the clarified sewage will be through tunnels outletting into the East river opposite Wards Island.

Collecting Sewers for the Eastern Bronx Subdivision. The sewage from a large portion of the Eastern Bronx subdivision will be collected at Clason Point by a system of combined sewers now under construction. These combined sewers will be provided with storm-water overflows at various points along the Bronx river and Westchester creek.

In accordance with plans outlined by the Bronx Bureau of Sewers, another portion of this subdivision, lying east of Westchester creek, will be drained by a trunk sewer outletting at Old Ferry Point; and the sewage of the remainder of the district, which drains to Eastchester bay, will be carried to an outlet on the south side of Throgs Neck.

A short intercepting sewer and a pumping station will be all that is required to transfer the dry-weather flow from the Old Ferry Point sewer to the sewer which is to discharge at Clason Point. At a later period another intercepting sewer could be constructed along the waterfront from the pumping station to a point near Throgs Neck, in order to intercept the dry-weather flow from the district draining to Eastchester bay. The cost of this sewer has not been included in the estimates, as it will not be necessary in the near future at least.

The sewage thus collected at Clason Point, after passing through grit chambers and coarse screens, will be pumped to treatment works located at that place, and the effluent discharged through submerged outlets into the East river.

The sewage of the district draining to Eastchester bay will be discharged untreated into deep water in the East river close to the junction of the East river with Long Island Sound. If at some future time it is thought advisable to discontinue the discharge of raw sewage at this point, a connection can be made with the pumping station at Westchester creek, as previously mentioned; or treatment works can be installed in the vicinity of the outlet.

Collecting Sewers for the Northwestern Queens Subdivision. The dry-weather flow from the Northwestern Queens subdivision will be brought to the East river at the foot of Winthrop avenue, Long Island City, by means of an intercepting sewer starting on Ditmars avenue north of Astoria avenue, Corona, and running along the shores of Flushing bay and Bowery bay, passing thence through Steinway to its final outlet. The sewage will be passed through grit chambers and fine screens before being discharged.

With the street grades as now established, all the sewage of this area, with the exception of that from several small districts along the waterfront, can be discharged into the East river by gravity. When these districts are developed, several small automatic pumping stations can be installed to pump the sewage into the main intercepting sewer. In order that the dry-weather flow from two large interior districts may be brought by gravity into the main interceptor, long dry-weather cut-off sewers will have to be constructed to intercept, at a considerable distance from the water-front, the combined trunk sewers which are proposed for the drainage of these districts. The topography is such that these cut-off sewers can intercept the dry-weather flow from the combined lateral sewers which will connect with the main trunk sewers below the points from which the cut-off sewers start.

Preliminary drainage plans covering this territory have been prepared by the Queens Borough Bureau of Sewers and approved by the Board of Estimate and Apportionment. The plan proposed by the Commission interferes but little with any of the combined sewers proposed by the Bureau, except the main sewer along the water-front, and affords a more favorable point for the discharge of the dry-weather flow. The storm water will be discharged directly into Flushing and Bowery bays. The main intercepting sewers along the shores of these two bays, as proposed by the Bureau of Sewers, becomes unnecessary. Steps have been taken by the Bureau of Sewers to build this sewer for the present only to a point on the southwesterly shore of Flushing bay, south of the outlet from Jackson Mill pond. This sewer will continue to dispose of the storm water from the areas draining to the southwesterly shore of Flushing bay, while the dry-weather flow from the laterals discharging into it would be intercepted by the sewer proposed by this Commission.

No satisfactory method of relieving the intercepting sewer for the Northwestern Queens subdivision, at a reasonable cost, is apparent, and therefore this sewer has been designed by this Commission to have sufficient capacity to provide for a dry-weather flow which is not likely to be exceeded for a great many years.

Collecting Sewers for the Corona-Flushing Subdivision. The house sewage from practically the whole Corona-Flushing subdivision will be brought to Tallman Island by a main trunk sewer which will start in Winfield and run through Elmhurst and across the marshes, south and east of Corona, to Flushing creek. The sewer will pass under the creek by means of a siphon and will follow its easterly bank through Flushing. From this point the sewer will cross the marsh to College Point and continue to Tallman Island.

The sewage from the tributary areas will be brought to the main sewer by many trunk and lateral sewers. One of the more important of these branch sewers will start near Forest Park and join the main trunk sewer on the meadows not far from Strongs Causeway. Another, joining the main sewer just after it crosses Flushing creek, will drain the Mill creek valley and provide a much-needed outlet for the dry-weather flow from the existing Ingleside trunk sewer. Still another sewer, with several main branches, will drain that part of Corona which lies north of the Long Island Railroad and, after passing under Flushing creek as a siphon, will join the main sewer at the corner of Broadway and Lawrence street, Flushing.

Most of College Point will be drained by two trunk sewers, one of which will tunnel through the hill from the foot of Fifth avenue, while the course of the other will be along the shore, serving the westerly and northerly portions of College Point.

After considerable study, it has been found feasible, with the street grades as established, and with the main sewer at reasonable depth, to collect practically all the sewage to Tallman Island without pumping. Some of the low land near the head of Flushing creek is so far from the main trunk sewer that its sewage will have to be pumped to that sewer.

At Tallman Island the sewage, after passing through grit chambers and coarse screens, will be pumped into the treatment tanks to be installed there. The clarified effluent will be discharged into the East river through submerged outlets at a considerable distance from shore.

Favorable conditions exist for the future relief of the main trunk sewer in this subdivision. This is fortunate, as the territory is very large, the main sewer long and the present population scattered and comparatively small. The trunk sewers which will join the main sewers, and the main sewer itself west of Elmhurst, have been designed to serve populations which are not likely to be exceeded for many years.

A future relief sewer is designed to start on the Queens boulevard at Caldwell avenue, southeast of Elmhurst, and run in an easterly direction, relieving the main trunk sewer of practically all the sewage which will flow into it from the south between Caldwell avenue and Mill creek. This relief sewer will cross Flushing creek near Strongs Causeway and enter a pumping station to be built near the confluence of Mill and Flushing creeks. The Mill creek valley sewer will also be diverted so as to enter the station.

From the pumping station near the junction of Mill and Flushing creeks, the sewage will be lifted into a high-level relief sewer, which will flow through Flushing and follow the high land west of Whitestone to the treatment works at Tallman Island. This future high-level intercepting sewer will be continued, above its junction with the force main from the pumping station just mentioned, in a southerly and easterly direction through Flushing, Ingleside and Flushing Heights. The sewage from the high land between the Mill creek valley and Cedar Grove Cemetery may be collected and siphoned across the lower end of this valley into the high-level sewer in Flushing.

The high-level relief sewers, just described, will deliver by gravity to the treatment works the sewage from practically all the high land of the Corona-Flushing subdivision which lies east of Flushing creek.

The original main trunk sewer from Winfield to Tallman Island will be of sufficient size to carry the sewage which, for many years, may be expected to originate within the territory which will not be served in the future by the relief sewers, as described. It will be large enough, moreover, to carry the sewage from the whole Corona-Flushing subdivision for a long time.

Collecting Sewers for the Northeastern Queens Subdivision. The sewage from the Northeastern Queens subdivision will be carried to Cryders Point by two main intercepting sewers. One of these, the Whitestone interceptor, will start near the waterfront west of Whitestone Point and run along the Whitestone shore and through Beechurst to Cryders Point. Near Whitestone Landing a trunk sewer, draining a large inland district between Whitestone and Ingleside, will join the intercepting sewer.

The other main intercepting sewer will extend along the shores of Little bay and Little Neck bay, from Cryders Point to a point in Bayside just north of Oakland Lake. At this place a trunk sewer will extend to the west, draining the large district between Ingleside and Bayside. At Broadway, in Bayside, the sewage from Douglaston, Little Neck, and the low land lying between Bayside and Douglaston, will be received into the main intercepting sewer through a force main which will run from an automatic, electrically-operated pumping station near Alley creek. To this pumping station the sewage from Douglaston and Little Neck will be brought by an intercepting sewer starting east of Douglas Manor and following closely the shore of Little Neck bay to the pumping station.

Practically all the sewage of the Northeastern Queens subdivision, with the exception of that from Douglaston, Little Neck, and the low lands around Alley creek, can be brought to Cryders Point, and there passed through screens and discharged into deep water by gravity. The sewage from a very small area near Whitestone Landing, and from several low-lying districts along the shore of Little bay and Little Neck bay, will have to be pumped into the high-level sewers when the population on these areas becomes large enough to require sewerage facilities. Also, a small marshy district near the city boundary, east of Douglas Manor, cannot be drained into the Douglaston intercepting sewer. These small districts will be served by inexpensive automatic pumping stations.

All the trunk and intercepting sewers of this subdivision, excepting the lower end of the intercepting sewer from Bayside to Cryders Point, have been designed to serve a population which is not likely to be exceeded for many years. From Shore avenue northward it is proposed to relieve this sewer by a parallel sewer running to Cryders Point, but such a relief sewer will not be necessary for a long period.

Areas, Populations and Quantities of Sewage

The following table gives, for the several subdivisions, the areas, the estimated population and average dry-weather sewage flow upon which the design of the sewers was based, and the capacities of treatment works which the Commission has used as a basis for estimating the cost of the projects proposed for the Upper East river and Harlem division:

TABLE V

Areas, Populations and Quantities of Sewage

Subdivision	Area (Without Parks, etc.), Acres	Population			Average Dry-weather Flow of Sewage, Mgd.*		Capacity of Treatment Works on	
		In 1910, from U. S. Census	In 1940 (Estimated)	Which Sewers are Designed to serve	In 1910	In 1940	Which Sewers are Designed to carry	Which estimate is based, Mgd.*
Harlem	12,100	995,300	2,105,800	2,838,000	124.4	302.2	404.6	200
Eastern Bronx	10,600	30,300	73,600	....	3.8	12.8	....	20
Northwestern Queens	3,100	10,000	28,500	253,000	0.5	5.0	34.0	15
Corona-Flushing	16,800	62,200	179,800	282,400	4.0	27.5	39.0	40
Northeastern Queens	5,900	8,000	22,900	62,800	0.3	4.5	9.6	10
Totals	48,500	1,106,800	2,410,600	....	133.0	352.0	....	285

*Million gallons per 24 hours.

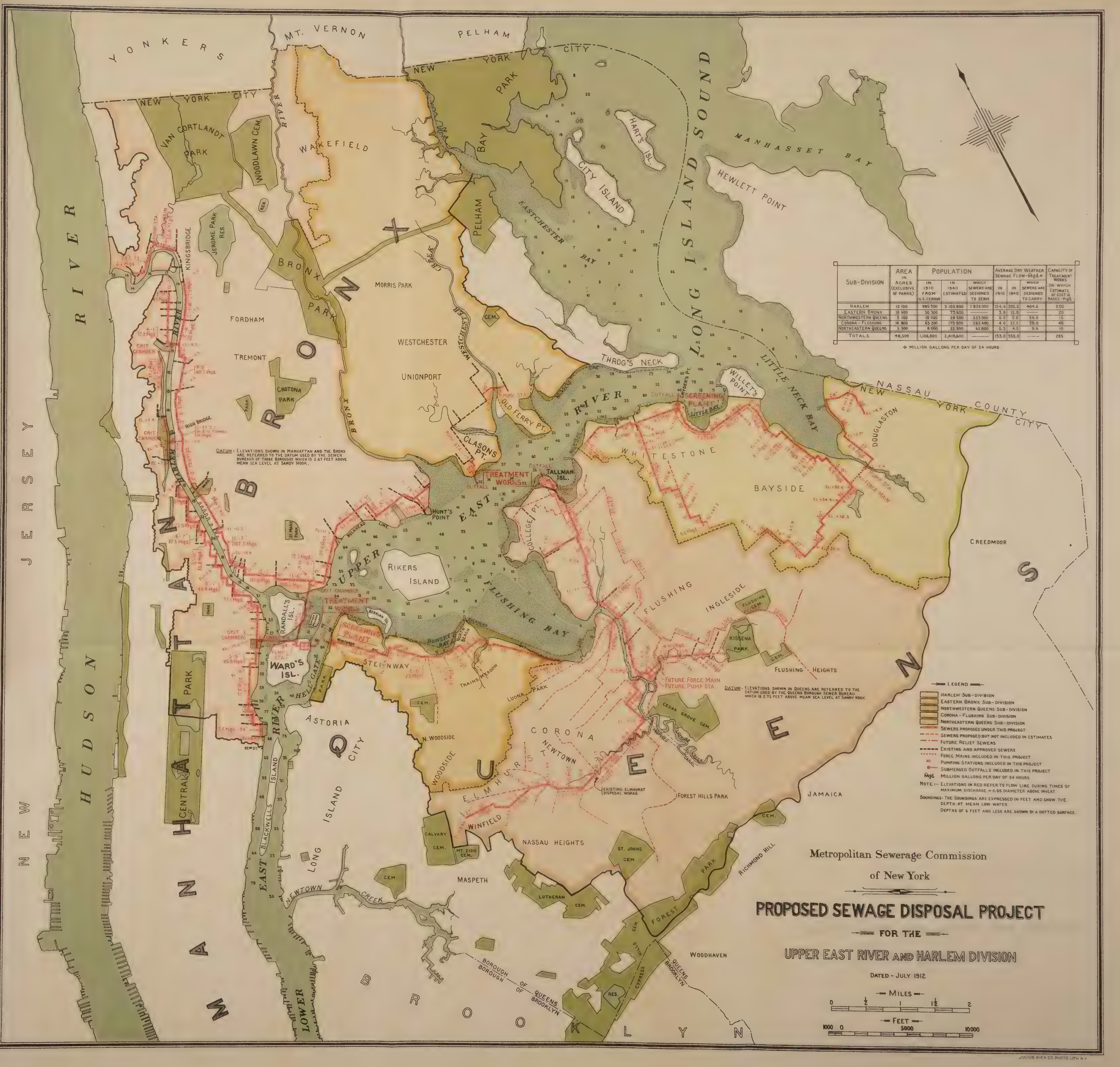
Preliminary Estimates of Cost of Main Drainage Works

The following table gives a summary of the estimated cost of construction and of the annual charges for maintenance and operation for the works suggested in this report. The costs of land and rights of way are not included.

TABLE VI

Estimates of Cost

Subdivision	Cost of Construction Including Engineering	Cost of Maintenance and Operation, Including Fixed Charges
Harlem	$9,814,000	$701,000
Eastern Bronx	708,000	87,000
Northwestern Queens	352,000	29,000
Corona-Flushing	1,961,000	154,000
Northeastern Queens	563,000	42,000
Totals	$13,398,000	$1,013,000



Metropolitan Sewerage Commission

of New York

PROPOSED SEWAGE DISPOSAL PROJECT

FOR THE

UPPER EAST RIVER AND HARLEM DIVISION

DATED – JULY 1912

SUB-DIVISION	AREA IN ACRES (EXCLUSIVE OF PARKS)	POPULATION			AVERAGE DRY WEATHER SEWAGE FLOW – Mgd +			CAPACITY OF TREATMENT WORKS ON WHICH ESTIMATE OF COST IS BASED – Mgd
		IN 1910 FROM U.S. CENSUS	IN 1940 ESTIMATED	WHICH SEWERS ARE DESIGNED TO SERVE	IN 1910	IN 1940	WHICH SEWERS ARE DESIGNED TO CARRY	
HARLEM	12 100	995 300	2 105 800	2 838 000	124.4	302.2	404.6	200
EASTERN BRONX	10 600	30 300	73 600	———	3.8	12.8	———	20
NORTHWESTERN QUEENS	3 100	10 000	28 500	253 000	0.5	5.0	34.0	15
CORONA – FLUSHING	16 800	63 200	179 800	282 400	4.0	27.5	39.0	40
NORTHEASTERN QUEENS	5 900	8 000	22 900	62 800	0.3	4.5	9.6	10
TOTALS	48,500	1,106,800	2,410,600	———	133.0	352.0	———	285

+ MILLION GALLONS PER DAY OF 24 HOURS

LEGEND

- ▭ HARLEM SUB-DIVISION
- ▭ EASTERN BRONX SUB-DIVISION
- ▭ NORTHWESTERN QUEENS SUB-DIVISION
- ▭ CORONA – FLUSHING SUB-DIVISION
- ▭ NORTHEASTERN QUEENS SUB-DIVISION
- ━ SEWERS PROPOSED UNDER THIS PROJECT
- ╌ SEWERS PROPOSED BUT NOT INCLUDED IN ESTIMATES
- ╌ FUTURE RELIEF SEWERS
- ╍ EXISTING AND APPROVED SEWERS
- ∘∘∘ FORCE MAINS INCLUDED IN THIS PROJECT
- ■ PUMPING STATIONS INCLUDED IN THIS PROJECT
- ● SUBMERGED OUTFALLS INCLUDED IN THIS PROJECT
- Mgd MILLION GALLONS PER DAY OF 24 HOURS

NOTE :– ELEVATIONS IN RED REFER TO FLOW LINE DURING TIMES OF MAXIMUM DISCHARGE = 0.65 DIAMETER ABOVE INVERT.

SOUNDINGS: THE SOUNDINGS ARE EXPRESSED IN FEET AND SHOW THE DEPTH AT MEAN LOW WATER.

DEPTHS OF 6 FEET AND LESS ARE SHOWN BY A DOTTED SURFACE.

DATUM: ELEVATIONS SHOWN IN MANHATTAN AND THE BRONX ARE REFERRED TO THE DATUM USED BY THE SEWER BUREAUS OF THOSE BOROUGHS WHICH IS 2.67 FEET ABOVE MEAN SEA LEVEL AT SANDY HOOK.

DATUM. ELEVATIONS SHOWN IN QUEENS ARE REFERRED TO THE DATUM USED BY THE QUEENS BOROUGH SEWER BUREAU WHICH IS 2.75 FEET ABOVE MEAN SEA LEVEL AT SANDY HOOK.

JULIUS BIEN CO. PHOTO. LITH. N.Y.

CHAPTER IV

THE RICHMOND DIVISION

General Description of the Territory

Location and Area. This report deals with that part of Staten Island which slopes toward the Narrows, Upper bay, Kill van Kull and Newark bay, or nearly the whole of the northern and northeastern portions of the Borough of Richmond. This territory includes, besides the natural drainage areas tributary to the bodies of water mentioned, a comparatively small area which drains naturally to Willow brook, and thence to Fresh Kills and Lower New York bay, and from which it is feasible and desirable to carry the house sewage to the Kill van Kull for final disposal.

The line bounding the district on the south starts from Fort Wadsworth at the Narrows, and runs in a generally westerly direction through Arrochar and Grasmere, across Todt hill and through the grounds of the Richmond Borough almshouse, finally reaching the village of New Springville. On the west the boundary line follows closely the Port Richmond road, passing through Bull's Head and Graniteville, and thence not far from Morningstar road to a point south of Elm Park, from which point it follows the watershed along the Staten Island Rapid Transit Railroad, westerly nearly to South avenue, whence it runs in a northwesterly direction, crosses Richmond terrace near Holland avenue, and continues to the shore of Newark bay east of Howland Hook.

Between this line and the established bulkhead line bordering the Narrows, Upper bay, the Kill van Kull and Newark bay there is included an area of 9,178 acres, or about 14.3 square miles, exclusive of cemeteries, parks, institutional property, U. S. Government land, etc. This area is approximately equal to one-fourth of the total land surface of Staten Island.

Topographical Features. The topography of the territory is varied. The part which drains to the northeastern shore of Staten Island is separated from that which drains to the north shore by a high ridge, which traverses the island in a general northeasterly and southwesterly direction and which rises at Todt hill, on the southern boundary of the territory, to an elevation of 409.8 feet above the Richmond high-water datum. The slopes on the easterly side of the ridge, within the limits of the territory, are precipitous. The westerly and northerly slopes are generally gradual.

In the western part of the territory the land is comparatively low, and in many places, near the watercourses and shores, it is swampy. The slopes down to these swampy areas are generally gradual, and the ridge marking the outline of the district on the west is not high.

The terminal moraine forms a conspicuous feature of the topography in the southeastern part of the district. Along the boundary line from Arrochar to Grasmere the bare, rounded hills and numerous depressions and ponds, characteristic of morainic topography, are especially noticeable.

The land near the shore, from Fort Wadsworth to Howland Hook, is made up alternately of headlands, of varying height, and valleys. Streams flow through many of these valleys, while in others the natural watercourses have been replaced by sewers. Much of that portion of the territory which drains to the Kill van Kull lies within the drainage area of Bodine creek, which is the largest watercourse in the subdivision.

Population. Nearly all the more thickly settled part of Staten Island lies within the drainage districts of the Narrows, Upper bay, Kill van Kull and Newark bay. Out of a total population in the Borough of Richmond, in 1910, of 85,969, this territory contained an estimated population of 64,320, or almost exactly three-fourths of the total. In 1940 it is probable that this area will have no less than 140,000 people out of 190,000, the minimum number that may be expected to inhabit the borough at that date.

While for a number of years previous to 1905 the growth of population in the borough was slow, due to various causes, since that date the population has increased at a comparatively rapid rate. Owing to changed conditions, it seems reasonable to expect that this rapid growth will continue.

Development. The land which lies near the shore from Rosebank almost to Howland Hook is well populated, and in some places thickly settled, but no part of the whole area has a population closely approaching in density that which exists in most of the other boroughs of New York City. In fact, with the exception of a few centers which are chiefly devoted to business purposes, and a number of spots where buildings of a poor class are huddled together, the whole area, for a considerable distance back from the waterfront, may be termed suburban. Further from the water most of the territory is rural in character, and there are large tracts which are still wholly unimproved.

While the populated sections will gradually extend farther and farther from the waterfront, much of the territory to the south and southwest is likely to remain in a rural and unimproved state for many years. It seems certain that the business centers will gradually expand, although nearness to Manhattan will cause activities to be confined mostly to the establishment of stores to supply the needs of the local population.

In course of time docks and warehouses will undoubtedly occupy the Stapleton waterfront, and water and rail facilities make the north shore a superior place for the establishment of factories.

Sewerage of the Territory. During the last few years large amounts of money have been spent by the borough in the construction of sewers. In the areas which drain to the Narrows and Upper bay, and along the western part of the north shore of the island, much progress has been made in replacing old and shallow village sewers, formerly built to take care of the immediate needs for house drainage, by modern systems. Except in some of the low areas near the waterfront, these new sewers are of the combined type.

In much of New Brighton, and in West New Brighton and Port Richmond, the old village sewers have so far remained more or less adequate to the needs of the communities. Few if any, new combined sewers have been constructed, and little has yet been done concerning the preparation of drainage plans for these areas. The natural watercourses which traverse those areas have proved sufficient for the removal of the storm water and they can continue for some time to perform this service for many places. Certainly, if the storm water in the thickly settled areas near the waterfront is removed by sewers, the run-off from the more sparsely settled upland territory can be adequately provided for in the natural watercourses for many years to come.

Wherever new and complete systems of sewers have been installed the dry-weather flow has been diverted from them, above mean high tide, and carried in a pipe to moderately deep water, and the outlet for the storm water has been placed near the shore line. It is the intention of the borough authorities to extend the dry-weather and storm-water outfalls to the pierhead and bulkhead lines, respectively, when the piers and bulkheads are built. By this method of discharging the house sewage into deep water during dry weather, the shores near the sewer outlets have escaped much of the pollution which otherwise would have been inevitable. Nevertheless it is felt that at many points the discharge of house sewage in a crude state, even at the pierhead line, will not be permissible much longer. For this reason an experiment station has been established by means of which the most suitable method of handling the local sewage disposal problem can be studied.

SEPARATION OF THE TERRITORY INTO SUBDIVISIONS

The topography of the whole division is unfavorable for the collection of all the sewage to one central point for disposal. The high ridge separating the areas draining to the northeastern shore of the island from those draining to the north shore, the small areas of low land in the western end of the division, the great distance which it would be necessary to carry much of the sewage and the amount of pumping required are opposed to the collection of the sewage at a point near the Narrows, which is the most favorable place available for its ultimate discharge.

While the discharge of all the house sewage from the northerly and northeasterly slopes of Staten Island into the Narrows would be desirable, and economy of operation would result from having only one disposal plant to maintain, it is believed that the benefits derived would not compensate sufficiently for the cost of carrying the sewage to such a plant. Moreover, it seems certain that the Kill van Kull, with its deep water and swift currents, would provide, for many years, if not for all time, a sufficiently favorable place for discharging the sewage from the areas bordering on Newark bay and the Kill van Kull, after it has been passed through settling tanks.

The territory with which this report deals has been subdivided in such a way as to facilitate the collection of the sewage, to provide for each subdivision a favorable and adequate place for treatment works, and to minimize the amount of pumping necessary. At the same time care has been taken not to divide the territory to such an extent as to cause the establishment of plants too small to be operated economically.

The subdivisions, five in number, have been given names associated with the points chosen for the sites of the respective treatment works. They are named and described as follows:

1. *The Quarantine Subdivision* comprises the area naturally draining to the Narrows from Fort Wadsworth to the Marine Hospital, Stapleton. The settlements known as Clifton, Rosebank and Fort Wadsworth lie within its boundaries.

2. *The Stapleton Subdivision* comprises the area naturally draining to the Narrows between the Marine Hospital and St. George. Tompkinsville, Stapleton and Concord lie within this area.

3. *The Livingston Subdivision* comprises the area naturally draining to Upper New York bay west of St. George, and most of that draining to the Kill van Kull east of a line joining the southerly end of Silver Lake, the corner of Castleton and Bement avenues, and the northerly end of Elm Court, West New Brighton. Sailors' Snug Harbor and the settlements of New Brighton and Livingston are included.

4. *The West New Brighton Subdivision* comprises, roughly, the area naturally draining to the Kill van Kull between the westerly limit of the Livingston subdivision and Tower Hill, Port Richmond, together with the area draining to Willow brook, east

of Port Richmond road. West New Brighton and Castleton Corners and parts of Port Richmond, Graniteville, Bull's Head and New Springville are in this subdivision.

5. *The Elm Park Subdivision* comprises, roughly, the area naturally draining to the Kill van Kull and Newark bay between Tower Hill and Holland avenue. Elm Park and parts of Port Richmond and Mariner's Harbor are within its confines.

The boundaries of the Quarantine, Stapleton and western part of the Elm Park subdivisions are fixed by the limits of the sewerage districts already outlined by the engineers of the borough; but the boundaries of the Livingston and West New Brighton subdivisions, except where bordering on the Stapleton subdivision, and of the eastern part of the Elm Park subdivision, have been placed by this Commission as seemed best suited to the main drainage plans to be worked out. The limits agree, however, in a general way, with sewerage districts which have been outlined, but as yet only approximately, by the engineers of the borough.

Outline of the Proposed Plan for Main Drainage

The proposed plan for the Quarantine subdivision provides for the collection of the sewage by a high-level intercepting sewer to the foot of Nautilus street, near the Quarantine station, where, after passing through coarse screens, grit chambers and fine screens, it will be discharged into the deep water of the Narrows. The sewage from the low land in Clifton will be pumped to the high-level sewer.

In the Stapleton subdivision the sewage will be collected near the foot of Water street, Stapleton, by high- and low-level sewers, passed through settling tanks and discharged into the Narrows off Canal street.

The plan for the Livingston subdivision provides for the collection of the sewage, mostly by high-level sewers, to the waterfront at Kissel avenue, Livingston, where, after being passed through settling tanks, it will be discharged into deep water in the Kill van Kull.

According to the proposed plan, the sewage from the West New Brighton subdivision will be brought, by high- and low-level intercepting sewers, to the waterfront near the garbage incinerator in West New Brighton, passed through settling tanks and discharged into deep water in the Kill van Kull.

In the Elm Park subdivision the sewage will be collected, by high- and low-level sewers, to the vicinity of Newark avenue and Richmond terrace, where, after being passed through settling tanks, it will be discharged into deep water in the Kill van Kull.

The sewers will vary from 8 inches to 6 feet 9 inches in diameter, and their total length will be 10.88 miles.

Main Drainage Systems

Kind of Sewers Proposed. The collecting and intercepting sewers, as planned for the five subdivisions, are designed, primarily, to carry eventually only the dry-weather flow from the contributing sewers, already built or to be built, in these subdivisions. Attention has been directed to the fact that the sewers built by the borough have been, in general, of the combined type, and that future construction is planned along the same lines. This means that during wet weather much of the house sewage, mixed with varying volumes of storm water, will continue to the bulkhead line without being intercepted, and will there be discharged. The growth of population to be expected in the borough has so influenced the design of the proposed dry-weather trunk sewers that many of them will assist materially, for a considerable period, in the disposal of the storm water.

While it would be inadvisable in those districts that have already been sewered by the borough authorities to provide systems of separate sewers, using those already built to remove storm water, this Commission considers it desirable, from now on, to construct sewers on the separate plan, and provide only such storm-water sewers as are demanded from time to time. Relieved of an admixture of house sewage, it is likely that many of these storm sewers might empty directly, for many years to come, into the natural watercourses which flow northerly into the Kill van Kull. The building of the comparatively small sewers required for the house drainage, and only such storm-water sewers as are absolutely needed, would minimize the cost of sewer construction, a consideration of much weight, especially in view of the fact that the population which can be assessed is small. Among other advantages which the separate system would possess may be mentioned better protection against pollution to the water near shore during wet weather and less quantity of sewage to be handled in the treatment works.

The plans here proposed have been worked out on the assumption that the present policy of constructing combined sewers will be continued, but whether or not this policy is followed in the areas to be sewered in future, the principal features of the main drainage systems and of the treatment works would be the same. If the sewers were built on the separate system, however, connecting chambers, overflows, tide-gates, and perhaps grit chambers, would be unnecessary, and the costs would be reduced to that extent.

Population and Quantity of Sewage. The sizes to be provided for the main trunk sewers for collecting the dry-weather flow in localities similar in position and condition to the settlements on the northern and northeastern shores of Staten Island should not depend, as has been the case in many cities, upon an estimate of population at any definite period, but upon densities of population on the tributary drainage areas which are considered probable when the areas shall have reached approximately their ultimate development.

The part of Staten Island included within this division is so near Manhattan, and there are so many other reasons, including the possibility of rapid transit, which may greatly accelerate the growth of population in any part of or throughout the district that it would be unwise to restrict the capacities of the proposed trunk sewers to suit what now appears to be the needs of the district thirty years hence. The total construction cost of the sewers as designed will not be a very large sum, and the saving effected by cutting down their capacities materially would not be as great as might be supposed.

In order to estimate the necessary capacities of treatment works, pumping equipment and other parts of the main drainage works that can easily be added to at later periods, it is essential that estimates be made of present populations and sewage flows. The following table presents these figures as estimated for the various subdivisions for the year 1910, based on United States Census figures. The areas of the subdivisions are calculated to the established bulkhead line, but do not include cemeteries, parks, Sailors' Snug Harbor, U. S. Government property, etc. The "area sewered" column of the table has no reference to the actual area in each subdivision that was provided with sewers in 1910, but the figures represent roughly the areas that were fairly well settled and might with reason be provided with sewers. The populations estimated for these sewered areas are the ones which have been used as a basis for estimating the flow of house sewage. It will be noticed that in the low-level areas the whole population was assumed to be served by sewers. The total sewage flow, manifestly, is not the average daily amount of sewage that was discharged from the sewer outlets of the district during dry weather in 1910, but the figures represent a rough estimate of the average amount that might have been expected under a more complete development of the sewerage systems.

The average flow of house sewage has been assumed to be 125 gallons per inhabitant per day, and the average ground-water leakage has been taken at 500,000 gallons per square mile per day, irrespective of local conditions.

TABLE VII

Population and Sewage Flow of the Five Subdivisions in 1910

Subdivision	Area, Acres	Area Sewered, Acres	Population	Population on Sewered Area	House Sewage Mgd.*	Ground Water Leakage Mgd.*	Total Sewage Flow Mgd.*
1—HIGH LEVEL TERRITORY.							
Quarantine	661	330	6,057	5,500	0.69	0.26	0.95
Stapleton	1,532	600	16,152	15,000	1.40	0.47	1.87
Livingston	893	600	11,183	10,000	0.93	0.47	1.40
West New Brighton	4,735	600	12,409	10,000	0.93	0.47	1.40
Elm Park	173	140	3,580	3,500	0.33	0.11	0.44
Totals	7,994	2,270	49,381	44,000	4.10	1.78	5.88
2—LOW LEVEL TERRITORY.							
Quarantine	156	80	1,404	1,404	0.13	0.06	0.19
Stapleton	182	110	3,241	3,241	0.30	0.09	0.39
Livingston	66	35	250	250	0.03	0.03	0.06
West New Brighton	321	240	5,082	5,082	0.47	0.19	0.66
Elm Park	459	280	4,962	4,962	0.46	0.22	0.68
Totals	1,184	745	14,939	14,939	1.39	0.59	1.98

TABLE VIII

Total Population and Sewage Flow of the Five Subdivisions in 1910

Subdivision	Area, Acres	Area Sewered, Acres	Population	Population on Sewered Area	House Sewage Mgd.*	Ground Water Leakage Mgd.*	Total Sewage Flow Mdg.*
Quarantine	817	410	7,461	6,904	0.64	0.32	0.96
Stapleton	1,714	710	19,393	18,241	1.70	0.56	2.26
Livingston	959	635	11,433	10,250	0.96	0.50	1.46
West New Brighton	5,056	840	17,491	15,082	1.40	0.66	2.06
Elm Park	632	420	8,542	8,462	0.79	0.33	1.12
Totals	9,178	3,015	64,320	58,939	5.49	2.37	7.86

The following table gives the densities of population, total population and average sewage flow used in designing the sewers of each subdivision. All the territory is assumed to be sewered. The area as far as the bulkhead line has been assumed to be populated. Much of the ground near the water will be occupied by industrial establishments instead of dwellings, but sufficient allowance for the sewage flow from these has probably been made by assuming the area populated throughout.

TABLE IX

Total Population and Sewage Flow Used in Designing the Proposed Sewers

Subdivision	Density of Population per Acre	Population			Average Sewage Flow Mgd.*		
		High Level	Low Level	Total	High Level	Low Level	Total
Quarantine	75–100	52,870	15,600	68,470	7.12	2.08	9.20
Stapleton	70†–150	112,385	19,870	132,255	15.24	2.63	17.87
Livingston	75–100	81,975	6,600	88,575	10.94	0.88	11.82
West New Brighton	40‡–120	247,960	38,260	286,220	34.69	5.04	39.73
Elm Park	80–120	18,040	40,060	58,100	2.39	5.37	7.76
Whole District	40–150	513,230	120,390	633,620	70.38	16.00	86.38

* Million gallons per day of 24 hours. † Average density on 1,116 acres.
‡ Average density on 1,814 acres. Average density of 50 on 1,283 acres.

Collecting Sewers for the Quarantine Subdivision. Most of the sewage of the Quarantine subdivision will be collected at the foot of Nautilus street by a high-level intercepting sewer, which will intercept the dry-weather flow from the combined sewer in Maple avenue at the corner of Anderson street and pass through Anderson street, Chestnut avenue, New York avenue, Sylvaton terrace and Bay street, and along the shore to Nautilus street. On its route it will receive the flow from all the territory lying south and west of its course.

The sewage from the low land in Clifton will be collected at the corner of Bay street and Maple avenue by an intercepting sewer in Bay street, which will intercept the dry-weather flow from existing sewers in Norwood avenue and Simonson avenue. At Bay street the dry-weather flow from the Maple avenue sewer will be diverted, and together with the flow from the Bay street intercepting sewer will be led into an automatic, electrically-operated pumping station to be located at this corner. From this pumping station the sewage will be pumped through a force main in Bay street to the high-level intercepting sewer at the corner of Bay street and Sylvaton terrace.

The dry-weather flow from the existing Nautilus street sewer, which drains a large area, will be intercepted and carried by a short connecting sewer to a junction with the high-level sewer above mentioned. The plan also contemplates the construction of a small high-level sewer in Centre street which will intercept the dry-weather flow from the combined sewer at the corner of Norwood avenue and discharge it at Simonson avenue, or a short distance north of it, into the combined sewer planned for Centre street. It will thence be carried to the Maple avenue sewer and finally into the high-level sewers in Anderson street.

The proposed collecting sewers in the Quarantine subdivision vary from 12 inches to 3 feet 3 inches in diameter. Their total length, including the force main, but exclusive of the outlet pipe, is 1.46 miles.

Collecting Sewers for the Stapleton Subdivision. A large part of the area included within the Stapleton subdivision is at a sufficient elevation to permit its sewage to be collected and passed by gravity through tanks located in Stapleton, but the elevations of the streets in the vicinity of the works are so slight that the sewage from the high-level districts will have to be carried to the works in long conduits submerged below the hydraulic gradient.

On the north the dry-weather flow from the Arietta street sewer will be intercepted at Stuyvesant place and brought, together with sewage collected on its route, by a high-level sewer passing through Stuyvesant place, Griffin, Hannah, Sarah Ann, Van Duzer and Elizabeth streets to a point a short distance east of Van Duzer street, from which place it will be carried to the treatment works, located on Front street between Prospect street and Water street, by a siphon passing through Elizabeth street, rights of way and Front street.

On the south the dry-weather flow from the large sewer in Broad street will be intercepted at the corner of Canal and Broad streets and carried to the treatment works by a siphon passing through Canal, Water and Front streets. From the corner of Riker and Broad streets a connection will be laid in such a way as to join the large Broad street sewer just above the point at which its dry-weather flow is intercepted.

At Wright and Beach streets this siphon will have connections through which the dry-weather flow from the existing sewers in these streets will be added. Ample head for this purpose can be secured without making these cut-off sewers of great length.

That part of the sewage of the subdivision which cannot be passed through the treatment works by gravity will be brought to an automatic, electrically-operated pumping station located at the works. Here the sewage will be raised by the pumps to such an elevation as to allow it to pass through the tanks.

The two low-level intercepting sewers required will be built in Front street and will be short. The one from the north will start, until its extension is required, by intercepting the dry-weather flow from the existing Elizabeth street sewer; the one from the south will intercept the dry-weather flow outlet sewer at present in Canal street, and will be joined by the existing 15-inch sewer in Water street. It is assumed that the 10-inch sewer in Thompson street, which now creates foul conditions by discharging into the dock, will be joined to the sewer in Canal street and the flow thus taken to the treatment works.

In designing the high-level siphons, the available head was found so small that the velocities through the siphons would have to be less than desirable. They would be especially small for a number of years. Trouble from this cause can be obviated by constructing by-passes from these siphons to the suction well of the pumping station at the treatment works. By means of these by-passes the siphons can be easily and effectively flushed.

It was found best to make the south siphon of a capacity sufficient to take care of the needs for only a few years with the idea that one or two more conduits can be constructed as required. With the north siphon conditions were somewhat different. It will be economical to provide this siphon with the same capacity as that of the intercepting sewer leading to it. In order to make the velocity of sewage as great as possible when the flow is small, the north siphon will consist of two pipes of different sizes, the larger one to come into use automatically when the level of the sewage in the high-level sewer reaches a certain height.

Both the north siphon, of 24-inch and 18-inch pipes, and the south siphon, of 24-inch pipe, could, it is thought, be built economically and properly of vitrified pipe, with bituminous joints and surrounded by concrete, and the estimates have been based upon this type of construction.

The proposed collecting sewers in the Stapleton subdivision vary from 15 inches to 2 feet 9 inches in diameter. Their total length, including siphons, but exclusive of outlet pipe, is 1.54 miles.

Collecting Sewers for the Livingston Subdivision. Practically all the sewage of the Livingston subdivision can be brought to the treatment works at the foot of Kissel avenue and passed through them by gravity.

The sewage from St. George and New Brighton will be collected by a high-level intercepting sewer, which will start at the corner of Jay and Wall streets and pass through Jay street and Richmond terrace to the treatment works.

From the south a high-level sewer will start at the corner of Kissel avenue and Brighton boulevard and pass through Kissel and Bergen avenues and Health place to the treatment works. A branch of this sewer will be constructed in Bergen avenue between Oakland avenue and Health place.

A small low-level intercepting sewer will be built in Richmond terrace from Oakland avenue to a small, automatic, electrically-operated pumping station located at the site of the treatment works.

In this subdivision the high-level sewers will have to pass through low land before reaching the treatment works. The street grades in these low areas have been at least tentatively established. However, the area is not yet built up and it will be feasible to raise the projected street grades wherever necessary, so as to give a light, but sufficient cover over the top of the sewers.

The proposed collecting sewers in the Livingston subdivision vary from 10 inches to 3 feet 3 inches in diameter. The total length, exclusive of outlet pipe, is 2.77 miles.

Collecting Sewers for the West New Brighton Subdivision. The sewage of the West New Brighton subdivision will be collected by two high-level and two low-level sewers. Just before reaching the treatment works, which are to be located south of Starin avenue, between Bodine and Dongan streets, the sewers join so as to form one high-level and one low-level sewer.

The east high-level intercepting sewer will start at the corner of Elm court and Henderson avenue and pass through Henderson avenue, Water street and Richmond terrace to a junction with the west high-level intercepting sewer.

The west, or perhaps better, the south high-level intercepting sewer, has been assumed, for the purposes of this report, to start at the proposed Northfield boulevard.

Its route will be through Linnet street, Madison avenue, Jewett avenue, Roberts street, Manor road, Castleton and Columbia avenues, Cedar and Bodine streets and Richmond terrace, and thence through the city's property at the West New Brighton garbage incinerator. A small branch of this sewer will be built in Palmer avenue east from Heberton avenue, so as to intercept the sewage flow from the high area west of the latter street.

The east low-level intercepting sewer will start at the foot of Broadway, at which point it is assumed that the flow from the combined sewers in the low area in the vicinity will collect, and will pass through Richmond terrace and Starin avenue to Dongan street, where it will join with the west low-level intercepting sewer.

The sewage from a large part of Port Richmond and the low area in the vicinity of Bodine creek and Palmer's run will be brought to an automatic, electrically-operated pumping station at the treatment works by the west low-level intercepting sewer which will start in Richmond avenue north of Richmond terrace and pass through Richmond terrace, Starin avenue and Dongan street.

Whether the large undeveloped areas in the West New Brighton subdivision, which lie south of the proposed Northfield boulevard, are finally sewered upon the separate or upon the combined plan, all the dry-weather sewage flow can be brought by gravity to the upper end of the west high-level intercepting sewer as proposed.

On account of the large population which eventually will occupy the extensive area tributary to it, this sewer is much larger than any of the collecting sewers in the other subdvisions, and can serve for many years to carry to the waterfront much of the storm-water brought to it by the combined sewers in West New Brighton. The surplus storm-water would be led to a trunk sewer, which would also collect the flow from the sewers of the low-level district. It is suggested that this trunk sewer be designed of a size sufficient to care for the ultimate dry-weather flow of the low-level district tributary to it, together with only such storm-water as it would probably have to carry for a few years, with the idea that later, when it becomes necessary to close up the watercourses and provide artificial channels for the storm-water from the large and now undeveloped areas, a large storm-water sewer can be built to the waterfront.

The conditions in much of this subdivision, with its numerous open watercourses, are such that great economy would result from the construction of sewers on the separate system. It will be particularly desirable, when the time arrives, to sewer on the separate system that portion of this subdivision which lies south of Richmond turnpike and drains directly to Willow brook. When it becomes no longer possible to provide for the storm-water from this area on the surface, it should be emptied into Fresh Kills instead of being carried with the house sewage all the way to the Kill van Kull.

In all the subdivisions it has been assumed that streets would be opened and graded according to the plans at present outlined by the borough. In this subdivision particularly, the routes of many of the proposed sewers are laid out in streets which are not yet opened.

Owing to topographical conditions in the different subdivisions, the high-level sewers, near their entrance to the various treatment works, have had to be placed lower with reference to the ordinary sewage level in the settling tanks than is desirable. With the small amount of sewage that will be carried through these sewers in dry weather for some time after their construction, small velocities will occur in their lower ends. This will cause trouble from deposits only for a short distance, if at all, in any of the sewers except the west high-level sewer of the West New Brighton subdivision, as all of them except the one named are small in size and their grades are considerable. While the dry-weather flow is small it might be practicable to run the tanks with a somewhat lower sewage level than that for which they are designed. Opportunity for creating a greater velocity at intervals might be afforded by a temporary lowering of the water level in the tanks or by providing a by-pass to the pumping stations, outfall pipes or to storm or combined sewers at a lower level.

The proposed collecting sewers in the West New Brighton subdivision vary from 8 inches to 6 feet 9 inches in diameter. Their total length, exclusive of the outlet pipe, is 3.14 miles.

Collecting Sewers for the Elm Park Subdivision. In the four subdivisions already considered it has been found practicable to collect and dispose of most of the sewage by gravity. Conditions in the Elm Park subdivision are different, resulting in the necessity of pumping considerably more than half the sewage.

A high-level intercepting sewer will start at the corner of Lafayette avenue and Harrison avenue, Port Richmond, to which point it is assumed that a combined sewer in Elizabeth street and Harrison avenue will bring sewage from points as far east as Broadway. The route of the high-level sewer will be through Harrison, Nicholas and Charles avenues, Douglas street and Newark avenue to the treatment works at the corner of Newark avenue and Richmond terrace. A short branch of this sewer in Roselle and Monroe streets, as far as the railroad, will bring to it the dry-weather flow from existing sewers in Monroe and Cedar streets.

From the east the sewage from the low-level district will be brought to an automatic electrically-operated pumping station at the treatment works by a sewer in Richmond terrace starting at Nicholas avenue. From the west the sewage will be carried to the pumping station by a sewer in Richmond terrace. This sewer will intercept the dry-weather flow from the existing combined trunk sewers in Harbor road, Union avenue and Housman avenue.

The proposed collecting sewers in the Elm Park subdivisions vary from 8 inches to 3 feet in diameter. Their total length, exclusive of the outlet pipe, is 1.97 miles.

Pumping Stations. All the pumping stations in the division will be of the automatic, electrically-operated type. The current for operating them can be purchased, or it might be furnished by the garbage incineration plants at West New Brighton and Clifton, thus affording a desirable outlet for some of the surplus power generated at those plants. This surplus power would undoubtedly be used at the West New Brighton sewage pumping station, as there would be no expense for transmission at this point. It would also probably pay to transmit power from the Clifton incinerator to the Maple avenue pumping station in the Quarantine subdivision. Whether it would be economical to transmit power from the West New Brighton incinerator to the Elm Park and Livingston pumping stations, and from the Clifton incinerator to the Stapleton pumping station, would depend upon the price for which current could be purchased from the light and power company.

All the pumping equipment ultimately necessary in these stations would not be required at first. However, all pumps and motors should be in duplicate.

The following table gives the average total head pumped against, the estimated average sewage flow which would have arrived at each pumping station in 1910 under the assumptions given in the discussion of population and sewage flow, the average sewage flow at each station which was used as a basis for estimating the cost of operation, and the aggregate average sewage flow for which the sewers leading to the station were designed.

TABLE X

Main Pumping Stations

Pumping Station	Total Head, Feet	Average Sewage Flow—Mgd.*		
		Estimated for 1910	Basis for Cost of operation	Contributing Sewers Designed for
Maple Avenue	10.0	0.19	0.50	2.08
Stapleton	12.0	0.39	1.00	2.63
Livingston	14.0	0.06	0.25	0.88
West New Brighton	13.5	0.66	2.00	5.04
Elm Park	14.5	0.68	2.00	5.37
All Stations	....	1.98	5.75	16.00

* Million gallons per day of 24 hours.

Outlets. All the outlet pipes through which the effluent from the various treatment works will be discharged will extend into deep water where the currents are swift.

In the Quarantine subdivision it is proposed to make use of an existing 20-inch cast-iron outlet sewer which extends out to a point about 225 feet from the present shore line. This pipe will be of sufficient capacity to last for many years, and it should be extended to, or nearly to, the pierhead line. When necessary, another outlet pipe can be added.

There is at present a 3-foot wood stave pipe running to the outer end of the municipal ferry pier at the foot of Canal street, Stapleton, through which pipe the dry-weather flow from the tributary sewers is carried to deep water. This pipe is of sufficient size to carry the effluent from the proposed Stapleton treatment works for many years, and could be made of use. When the pier is extended to the established pierhead line the outlet pipe should be extended also. When necessary another outlet can be built at the foot of Prospect street.

From the Livingston treatment works it is proposed to lay a submerged 24-inch cast-iron pipe to deep water beyond the pierhead line and, when necessary, another outlet pipe can be laid.

Although greatly increased capacity of outlets from the West New Brighton treatment works will ultimately be needed, a 3-foot pipe will be ample in size for a long time. It would probably be practicable to lay a wood-stave pipe under the existing pier at the foot of Bodine street and to extend the outlet for some distance into deeper water by means of a submerged cast-iron pipe.

From the Elm Park treatment works it is proposed to lay a submerged 20-inch cast-iron pipe into deep water at a considerable distance beyond the pierhead line. This pipe will be of sufficient size to last for a number of years. It can be supplemented by another pipe when greater capacity becomes necessary.

TREATMENT WORKS

Forms of Treatment Proposed. The form of treatment proposed for the sewage of all the subdivisions, except the Quarantine, is the same and consists of coarse screening and sedimentation. A period of about two hours should be allowed for settlement. It is believed that the deep water and strong currents along the shores of this district will afford ample opportunity for the diffusion and digestion of sewage in such quantities as may be expected from this portion of Staten Island, if it is treated in the manner proposed, and discharged from submerged outlets into water of 30 feet or more in depth and good current.

The successful protection of the water along these shores will, however, depend somewhat upon the measures taken elsewhere for the betterment of the harbor. The present pollution along the northern, and particularly the northeastern, shore of Staten Island is, to some extent, due to the condition of the harbor water in general.

Passage through grit basins, coarse and fine screens is the form of treatment proposed for the Quarantine subdivision, as the opportunity for diffusion and digestion of the sewage by the harbor waters is here especially favorable.

At the treatment works for all the subdivisions, grit chambers, with a settling period of from one to two minutes, will be provided. Where screening is to be used, the grit chamber will prevent heavy deposits which might occur in the outlet pipes or on the harbor bottom near the points of discharge. Where settling tanks are to be used, the grit chambers will guard against trouble that would occur from the deposition of heavy solids in the tanks which are intended for the sedimentation of organic matters.

Sites for Treatment Works. Many factors have affected the choice of sites for treatment works in the various subdivisions. Among the chief considerations have been the existence of undeveloped land of sufficient area for plants of the size which will ultimately be necessary, the location of these areas at such points as may be best suited to an economical collection of the sewage, this collection being accomplished, as far as possible, without the use of pumping machinery, proximity to any servicable sewage outlets that might occur, and favorable location with respect to railroad facilities.

At the foot of Nautilus street there is ample room for locating a screen for the Quarantine subdivision.

The best site for the location of settling tanks for the Stapleton subdivision seems to be on the west side of Front street between Water and Prospect streets. This location is contiguous to the railroad, and the greater part of the site is occupied by an old asphalt plant and storage yard, which is out of use and for sale. On the Water street front there are a few old tenements. By a judicious arrangement of tanks, it will be possible on the area available to treat all the sewage that is likely to reach this point. If for any reason the purchase of this land is deemed inadvisable, there are other unoccupied sites in the immediate neighborhood which probably could be obtained.

The proposed site for the Livingston treatment works is west of Kissel avenue between Richmond terrace, as it is to be relocated, and Livingston place. There may be opposition to the establishment of treatment works here, but it is the logical place for them and, if the tanks are properly operated, no offense should be created.

The best site for treatment works in the West New Brighton subdivision is near the garbage incinerator. Economy of operation should result from their location at this point. The block bounded by Starin avenue, Dongan street, Richmond terrace and Bodine street seems to afford the best site for the works and has therefore been selected. There probably will be plenty of room within this area, even without including the lots bordering on Richmond terrace, to treat any volume of sewage which needs to be collected at this point.

In the Elm Park subdivision the most favorable site seems to be at the east corner of Richmond terrace and Newark avenue, although there is a considerable amount of unoccupied land in the vicinity. A location much farther to the west would be inadvisable, if for no other reason than on account of unfavorable conditions which exist there for the discharge of sewage.

Capacities of Treatment Works. In designing the treatment works sufficient capacity should be provided to take care of the volume of sewage to be expected for a reasonable period in the future. Nevertheless, the tank capacity to be provided in the first installation should not exceed the economical limit, as units can be added when necessary.

The following table gives the estimated average daily amount of sewage which might have been brought to the various works had they been in existence in 1910, and also the capacities which were used as a basis for estimates of cost of construction and operation and which are deemed reasonable as capacities to be provided for in the first installations.

TABLE XI

AVERAGE SEWAGE FLOW

Subdivision	Average Sewage Flow—Mgd.*	
	Estimated for 1910	Treatment Wokrs, First Installation
Quarantine	0.96	3.0
Stapleton	2.26	6.0
Livingston	1.46	4.0
West New Brighton	2.06	6.0
Elm Park	1.12	3.0
All Sub-divisions	7.86	22.0

* Million gallons per day of 24 hours.

Disposal of Sludge. The sludge produced in this division may be disposed of in various ways. For many years the amount of sludge will be comparatively small. In 1910 the digested sludge from two-story settling tank installations in the four subdivisions for which they are proposed might have amounted to 18 tons a day. When the capacities of the first tank installations are reached the amount of sludge will probably be about 38 tons a day.

The treatment works in the district are so placed that the sludge can be transported by water or rail. It would be possible, therefore, to dispose of it either at sea or on land. The presence of two garbage incinerators, both almost directly on railroad lines, would make it feasible to burn the sludge and garbage together. Centrifugal dryers might be placed at each disposal plant to dry the sludge before transportation, or it might be more economical to install such dryers at one or both incinerators and transport the larger volume of wet sludge to the incinerators in proper cars.

There is a large amount of waste land along the railroad line in the northwestern part of the island, near Arthur Kill, which would be suitable for filling with the dried sludge from the settling tanks. If the sludge were transported hither without previous drying it would probably be necessary to establish drying beds near the railroad before the sludge could be made available for filling purposes.

If the sludge is to be disposed of at sea it would be advisable to collect it at one or two points, to avoid construction of piers and loss of time in the operation of sludge steamers. For the purposes of this report, it has been assumed that all the sludge would be delivered wet into tanks located at the Stapleton treatment works, from which tanks a sludge discharge pipe would run out on the municipal pier. By this plan no new piers would have to be built and the sludge steamers passing out of the harbor from other treatment works would have to deviate only slightly from their course to serve as carriers for the Staten Island sludge.

Cost of Main Drainage Works

The estimated cost of the main drainage works proposed in this report, not being based on detail designs, are necessarily of a preliminary nature.

The following tables give a concise summary of the estimated cost of construction and of the annual charges for maintenance and operation. The costs of land and rights of way are not included.

TABLE XII

Estimated Cost of Construction

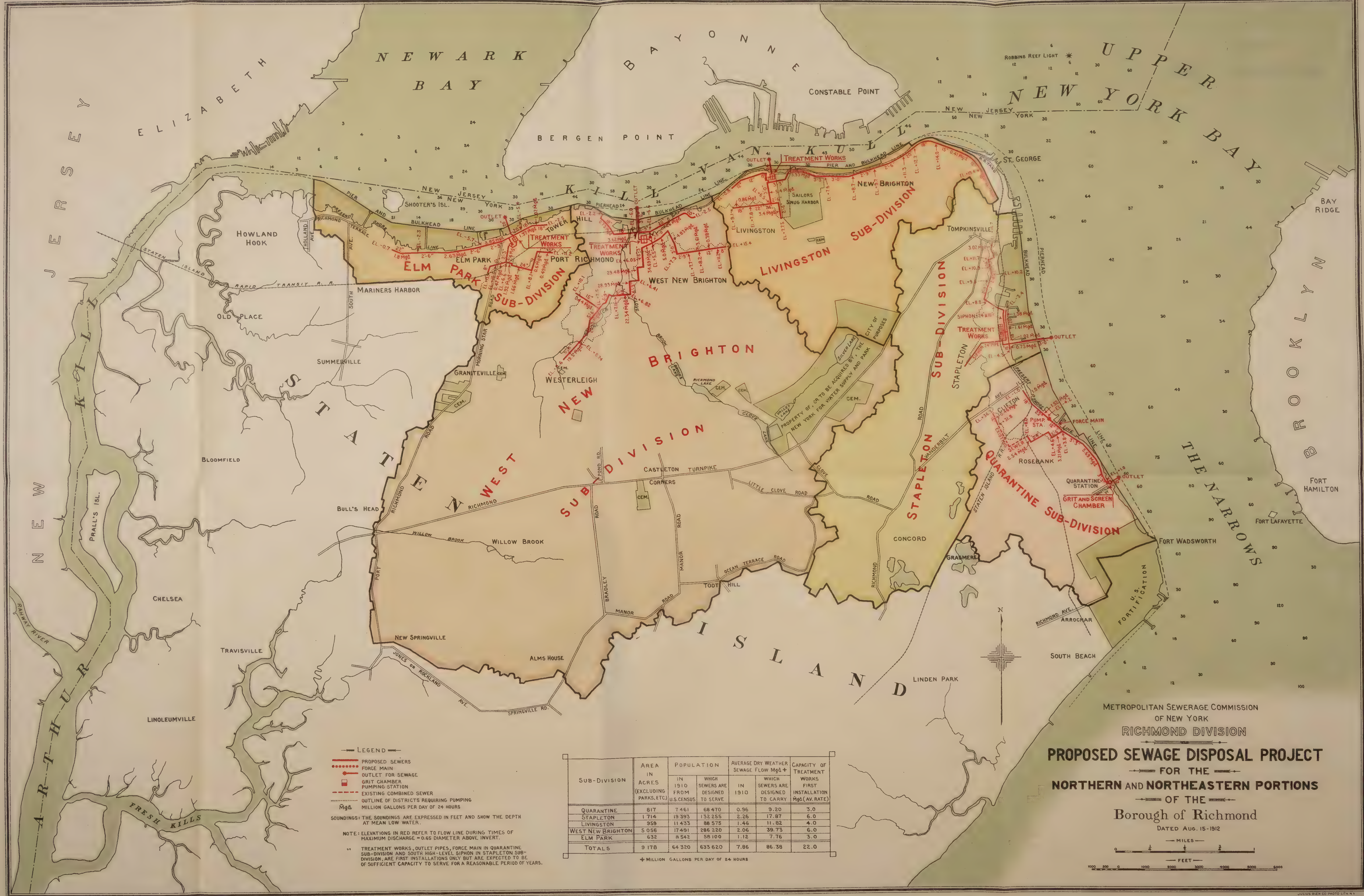
Subdivision	Sewers	Pumping Stations	Outfall Pipes	Grit Chambers	Treatment Works	Total Without Engineering, etc.	Engineering and Contingencies, 15%	Total Costs
Quarantine.............	$38,225*	$8,000	$6,000	......	$8,000‡	$60,225	$9,035	$69,260
Stapleton..............	62,430†	10,000	3,000	$3,500	63,000	141,930	21,290	163,220
Livingston.............	84,995	6,000	12,600	2,500	42,000	148,095	22,215	170,310
West New Brighton.....	164,305	12,000	17,400	3,500	63,000	260,205	39,030	299,235
Elm Park..............	62,125	12,000	13,500	2,000	31,500	121,125	18,170	139,295
Whole District....	$412,080	48,000	52,500	11,500	207,500	731,580	109,740	841,320

TABLE XIII

Estimated Annual Charges

Subdivision	Maintenance and Operation	Fixed Charges	Total
Quarantine....................................	$3,820	$3,505	$7,325
Stapleton.....................................	5,127	8,260	13,387
Livingston....................................	4,694	8,618	13,312
West New Brighton............................	7,584	15,142	22,726
Elm Park.....................................	5,742	7,048	12,790
Whole District...........................	$26,967	42,573	69,540

* Including Force Mains. † Including Siphons ‡ Grit and Screen Chamber.



METROPOLITAN SEWERAGE COMMISSION
OF NEW YORK
RICHMOND DIVISION

PROPOSED SEWAGE DISPOSAL PROJECT
FOR THE
NORTHERN AND NORTHEASTERN PORTIONS
OF THE
Borough of Richmond

DATED AUG. 15-1912

— MILES —
0 ¼ ½ ¾ 1

— FEET —
1000 500 0 1000 2000 3000 4000 5000 6000

— LEGEND —

▬	PROPOSED SEWERS
●●●●●●●	FORCE MAIN
✱—	OUTLET FOR SEWAGE
▣	GRIT CHAMBER PUMPING STATION
- - - -	EXISTING COMBINED SEWER
··········	OUTLINE OF DISTRICTS REQUIRING PUMPING
Mgd.	MILLION GALLONS PER DAY OF 24 HOURS

SOUNDINGS: THE SOUNDINGS ARE EXPRESSED IN FEET AND SHOW THE DEPTH AT MEAN LOW WATER.

NOTE: ELEVATIONS IN RED REFER TO FLOW LINE DURING TIMES OF MAXIMUM DISCHARGE = 0.65 DIAMETER ABOVE INVERT.

" TREATMENT WORKS, OUTLET PIPES, FORCE MAIN IN QUARANTINE SUB-DIVISION AND SOUTH HIGH-LEVEL SIPHON IN STAPLETON SUB-DIVISION, ARE FIRST INSTALLATIONS ONLY BUT ARE EXPECTED TO BE OF SUFFICIENT CAPACITY TO SERVE FOR A REASONABLE PERIOD OF YEARS.

SUB-DIVISION	AREA IN ACRES (EXCLUDING PARKS, ETC.)	POPULATION		AVERAGE DRY WEATHER SEWAGE FLOW Mgd ✣		CAPACITY OF TREATMENT WORKS FIRST INSTALLATION Mgd (AV. RATE)
		IN 1910 FROM U.S. CENSUS	WHICH SEWERS ARE DESIGNED TO SERVE	IN 1910	WHICH SEWERS ARE DESIGNED TO CARRY	
QUARANTINE	817	7 461	68 470	0.96	9.20	3.0
STAPLETON	1 714	19 393	132 255	2.26	17.87	6.0
LIVINGSTON	959	11 433	88 575	1.46	11.82	4.0
WEST NEW BRIGHTON	5 056	17 491	286 220	2.06	39.73	6.0
ELM PARK	632	8 542	58 100	1.12	7.76	3.0
TOTALS	9 178	64 320	633 620	7.86	86.38	22.0

✣ MILLION GALLONS PER DAY OF 24 HOURS

JULIUS BIEN CO. PHOTO LITH. N.Y.

CHAPTER V

THE JAMAICA BAY DIVISION

Boundaries of the Division

The territory included in the Jamaica bay division lies in the southeastern part of the City of New York.

The division is bounded by an irregular line following the watershed from 23d avenue and Gravesend bay, Borough of Brooklyn, to a point about three-quarters of a mile east of Prospect Park, thence northeasterly to the easterly boundary of New York City near Creedmoor, thence southerly following the city boundary to the ocean. The total area of land to bulkhead line is about 83.8 square miles. Of this area about 35.5 square miles lie in Brooklyn and 48.3 in Queens.

General Features of the Division

The principal topographical features of this division include a natural ridge, which forms the northern boundary of the territory, and from which the land slopes gradually to low-lying tidal meadows; the large, shallow expanse of Jamaica bay, studded with numerous marshy islands and hummocks, intercepted with narrow, crooked channels; and, finally, a protective barrier formed by the low, sandy shore of the Rockaway peninsula, separating the bay and the rest of the division from the open waters of the Atlantic ocean. In places, the low-lying meadows to the north of the bay extend for over two miles. Back of the meadows the upland begins and runs in a slightly elevated tract, which rises, on an average, four or five feet per thousand, until near the northern boundary of the division, where the elevation increases more rapidly.

The Jamaica bay division is partly built up. Parts of it include a thickly settled district in Brooklyn, parts consist of separated country villages, parts of strictly rural territory, including farms, and parts of large stretches of unprofitable salt marshes. Finally, there are some largely attended day summer resorts.

The population of the whole territory in 1910 was about 366,000, including 13,000 residents of Brooklyn, now draining to Gravesend bay, which it is proposed to include in the Jamaica bay system. The density of settlement, as shown by dividing the population by the area, gives but a poor idea of the extent to which the division is settled, for the reason that there are large, unpopulated sections and some rather densely peopled parts. The density thus divisionally determined varies between sixty persons per acre, at a point in Brooklyn, to one in ten acres near the head of Jamaica bay in Queens.

Probable Future of Jamaica Bay

Coney Island and Rockaway Beach, each of which is visited by hundreds of thousands of visitors on a summer holiday, are in this division. Parts of the division have increased largely in population during recent years and are still growing rapidly under the fostering operations of real-estate operators.

The shores of the bay are now devoted almost exclusively to the uses of a transient summer population and the waters to sailing, bathing and the cultivation of shell-fish.

The shell-fish interests of Jamaica bay are extensive. These waters, which first became famous for oyster culture about fifty years ago, are now much used for growing oysters and hard and soft shell clams. The beds are located on the bottom and sides of the natural main channels. The future development of the bay will make shell-fish culture unsafe from the standpoint of disease.

Unlike the cultivation of oysters and hard-shell clams, which is carried on by means of seed brought from elsewhere, the muddy shores of Jamaica bay afford seemingly endless supplies of soft-shell clams. These clams are free to anyone who will gather them. Persons may be seen digging soft clams in practically all parts of Jamaica bay during low tides.

In summer hundreds of small boats ply the waters on Sundays and holidays and the water front in those parts of the bay which are most easily accessible are settled with crowded communities which live in tents and cottages of an inexpensive nature.

The future of this division is uncertain, although there is a definite plan for the development of Jamaica bay for commercial purposes. This plan, which was proposed by a special body created for the purpose, and known as the Jamaica Bay Improvement Commission, involves extensive engineering works. It is proposed to construct a substantial and regular shore line, deep, wide channels for ocean-going vessels and harbor approaches for the entrance at Jamaica inlet.

It is also proposed to construct a number of canals on the northern shore, each about 300 or 400 feet in width and from 4,500 to 12,000 feet long, extending back into the territory at places where natural creeks exist, so as to increase the water front. The object of this development is to increase the shipping facilities of New York by providing additional wharves, storehouses, terminal facilities and space for the handling of vessels. At the present time no business of this kind exists, or is possible, in Jamaica bay, owing to the shallowness of the water, lack of railroad facilities and storehouse accommodations.

As to the future of the beaches known as Coney Island and Rockaway, it seems likely that they will long remain pleasure resorts, in spite of any commercial development which will occur in the neighborhood. The situation of Coney Island makes it comparatively remote from the shipping centers and the ocean front of Rockaway Beach renders it, to a considerable extent, independent of the natural resources of Jamaica bay which commercial conditions may destroy.

It is necessary to carefully consider how the waters of Jamaica bay are now used or are likely to be used in future in order to determine the degree of thoroughness with which these waters are to be protected from sewage pollution. If the waters are to be kept pure enough for bathing, boating and shell-fish culture, a different method of dealing with the sewage disposal problem of this division should be followed than if the bay is to be devoted to commercial purposes.

From a careful study of the Jamaica Bay Improvement Commission's reports it seems improbable that the waters of this division could be used both for shipping and the other purposes to which they are now put. The development of the bay for commerce would seem necessarily to exclude its use for pleasure; and, conversely, if the bay is to be maintained for purposes of recreation, its value will be seriously impaired by the developments of commerce. So far as the Metropolitan Sewerage Commission can foresee, the future of Jamaica bay will lie along the lines proposed by the Jamaica Bay Improvement Commission. It appears that an agreement to develop this harbor for shipping has been entered into between the U. S. Government and the City of New York; that outline plans have been officially adopted and money appropriated to begin the work.

That the development of the area draining to Jamaica bay will be rapid probably will not be disputed. The chief causes for this are: First, the improvements recently made, and those in contemplation, by the Long Island Railroad Co. and by the Brooklyn Rapid Transit Co.; and secondly, Jamaica is probably destined to be of considerable importance as the local focus of railroad lines to all parts of Long Island—to the west by the Pennsylvania tunnels and to New England by the bridge now under construction across the East river near Hell Gate. Already large sums of money have been appropriated for improvements in this vicinity.

The effect of this development will be felt all along the branch of the main line of the Long Island Railroad which extends east and west near the northern limit of the Jamaica bay division. The rapid transit lines and the southern branches of the Long Island Railroad will afford quick transportation from nearly all points in the drainage area to Brooklyn and Manhattan.

The projected Jamaica bay improvement already mentioned will provide economical entrance for coastwise and inland shipping. Building material can be delivered by water at low shipping rates, stimulating improvements on large areas accessible to the water front, which now are unoccupied and of little value.

It has been proposed to establish a barge canal terminal in Jamaica bay. The length of water front and the large marginal areas available cannot be found elsewhere. The trip from Norton Point to Rockaway Point via the ocean can be obviated by the construction of the Gravesend ship canal, which is understood to be included in the project for this section of Brooklyn that has been adopted by the city authorities.

Probable Future Population of the Division

In planning for the main drainage of this division, it has not seemed best to attempt to anticipate conditions more than forty or fifty years in advance of the present time, for the reason that conditions may arise which will result in an increase or shifting of population quite different from any that can now be foreseen. A material variation from forecast population is more to be expected in the thinly populated and rapidly improving areas than in those where, as in much of the Brooklyn area, populations are dense and the conditions which affect growth are well established. For this reason estimates for sewerage have been based upon a population in the Brooklyn portion of this division as forecasted for 1960, while in Queens the populations are forecasted for 1950.

The expected populations are, for the area lying in

Brooklyn	884,100
Queens	531,600
Total population planned for	1,415,700

General Outline of the Proposed Plan

An outline of the plan which is being worked out follows:

The sewage is to be collected by the separate system, so far as possible. Where this is not feasible the sewage provided for is confined to the dry weather flow. Allowance is made for an unavoidable inflow of ground water.

Where sewers have been constructed on the combined plan, it is proposed to intercept the dry-weather flow and provide storm water overflows above the points of interception. In this way a certain amount of house sewage mixed with storm water will pass to the bay during storms, but the amount which will enter in this way will be so small in comparison with the diluting water that no objectionable conditions are to be apprehended from this cause.

A serious consideration is the street filth and grit which will be carried down with the surface water. This might seriously pollute and form deposits in the bay. The dissolved organic matter will be taken care of by the large volume of water with which it will be diluted, but the floating solids and grit should be removed by screening and grit chambers placed near the outlets of the more important storm water drains.

The projected long canals mentioned earlier in this report will be most difficult to maintain in an unpolluted condition. There will be but little flow through them and practically no flushing effect from the tides. These long canals may become nuisances similar to Gowanus canal and Newtown creek, unless proper measures are taken to protect them.

The entire area can be divided into two subdivisions termed respectively the Eastern Jamaica subdivision and the Western Jamaica subdivision. Each will have a distinct system of collection and disposal.

The Western Jamaica subdivision will be the larger. It will collect the sewage from a population of 1,192,400 in 1960, located on about 49 square miles lying north of Jamaica bay and west of Cornell creek and east of Ulmer Park. The sewage from this territory may be expected to amount to as much as 166 million gallons per day in 1960. It will be delivered to a pumping station to be located near Flatbush avenue and Avenue X. From this point it will be pumped through force mains to Barren Island, where it will be treated, and the effluent discharged through submerged outlets into Rockaway inlet. For outlet island alternative project, see page 97.

In the Eastern Jamaica subdivision there will be about 38 million gallons of sewage collected daily in 1950. This will be from a population of 223,300 on the 27.4 square miles of Queens, which lie to the southeast of Cornell creek. This Eastern Jamaica subdivision is divided into two separate areas, one in Queens and one in Nassau County, which borders the head of the bay. The sewage from these is collected separately but carried to a common treatment plant on Jo Cos marsh. The northerly area is expected to contribute 21.6 million gallons of sewage per day from a population of 111,800 distributed over 19.6 square miles of territory, while the southerly area, comprising Far Rockaway and the Rockaway peninsula, is expected to contribute 16.5 million gallons per day from a population of 111,500 on 7.8 square miles.

From the northerly area the sewage will be brought to a pumping station near the Rockaway turnpike and Springfield road; and on the southerly area collecting sewers from the east and west will collect the sewage to a pumping station near Rockaway boulevard and Lucia avenue, Edgemere. From the pumping stations the entire volume will be pumped through submerged mains to a plant where the sewage will be treated on Jo Cos marsh. The effluent will be discharged into Broad channel.

The operation of the treatment works to be located at Barren Island and Jo Cos marsh will be restricted to house sewage, with such manufacturing wastes as it may be found best to admit into the sewers.

Western Jamaica Subdivision

It is intended that the intercepting sewer of this subdivision, called the Flatlands-Jamaica interceptor, shall start with a diameter of 5 feet 4 inches in the Old South road north of the present Jamaica Disposal Works. It will pass under the sewer from Jamaica and intercept the sewage from that division.

The sewage from the low-lying area to the south will be collected at the present disposal works for Jamaica. This station will then be converted into a pumping plant, and the sewage will be pumped into the interceptor. At Panama street the intercepting sewer passes under the Panama street sewers; then under the Brooklyn aqueduct, the location of which controls the elevation of the interceptor. At the borough line and Cozine street the diameter is to be 8′6″. The sewage collected at the present East New York disposal plant is to be lifted into the interceptor in Vandalia avenue.

Assuming that Fresh creek will be dredged for purposes of navigation, it will be best to cross under the creek by a siphon rather than carry the interceptor by a long detour around the head of the proposed basin.

At the head of Paerdegat basin, as well as at Hendrix street, the existing storm drains will pass over without interfering with the flow by depressing the arch of the interceptor, but the domestic sewage collected at this point will have to be pumped into the interceptor. On Avenue T, between Ralph street and Flatbush avenue, the diameter is to be 14′4″. The invert is to be about 16 feet below mean tide level.

At Avenue V and 11th street, Bensonhurst, a pumping station has been built to pump the sewage of the neighborhood to the 92d street outlet near the Narrows. The sewer leading to this outlet eventually will be too small, and it is proposed to divert this sewage by means of a sewer, called the Gravesend interceptor, to the east when conditions require the change. The sewers will increase from 4′0″ to 7′3″ diameter, and meet the interceptor from Jamaica at Flatbush avenue. The present Coney Island sewage disposal plants will be abandoned or utilized as pumping stations, delivering sewage to pumps to be installed at Ocean Parkway near Avenue W. The sewage delivered to the pumps at the present Shellbank creek plant will be pumped to the interceptor.

From Avenue T the sewage will flow through twin sewers about 10′3″ square to the main pumping station. Here centrifugal pumps of capacity to lift 350 million gallons per day 35 feet will be installed. This is the only pumping station required on the line of the interceptors. Two 7′2″ force mains will then convey the sewage to the disposal plant at Barren Island. (See Plate III.)

Barren Island is a most suitable point at which to treat and dispose of the sewage. The sewage will be carried to this point by what is called the Barren Island force main. The area of land here is ample; the land belongs to the city; garbage reduction works are already located there; there are no residences in the vicinity except for the workmen employed at the reduction plant; the land is of suitable elevation and believed to furnish, below the surface mud, good material for foundations; it is accessible for transportation by water; on the south it forms one shore of Rockaway inlet, which, on account of its depth, swift currents and proximity to the ocean, furnishes a suitable body of water into which to discharge the effluent.

The degree of purification that will be required is not known at this time. A rough computation indicates that if all the sewage which would naturally drain to Jamaica bay by 1960 were thoroughly diffused therein the sewage would, under ordinary conditions, be diluted by about 147 volumes of water at times of low tide. This would be about six to seven times the amount of theoretical dilution required to provide sufficient oxygen to digest the organic matter during the summer months, the most unfavorable of the year.

As this ideal condition cannot be relied upon, treatment to remove the grosser solids and a certain part of the dissolved impurities must ultimately be provided. In order to show approximately the cost of the works when this territory shall have become occupied to the extent above described, it is assumed that the sewage will then have to be subjected to clarification in settling tanks and further treatment by sprinkling filters and settling basins. About 100 acres of land will be ultimately required for the entire plant.

The effluent from the plant will flow through four submerged pipe lines and discharge in the deep water of Rockaway inlet. The inoffensive sludge from the settling tanks can be used for many years to fill in marsh lands near the plant, or, if preferred, it can be dumped at sea.

The estimated cost of construction of this system for the full future estimated population is:

Interceptors	75,450 lin. ft.	$4,321,660
Siphons	1,150 " "	77,600
Pumping stations	5	755,600
Force mains	9,400 " "	356,200
Treatment plant	......	4,623,100
Outfall pipes	3,000 " "	154,150
Contingencies	15%	1,541,690
Total cost		$11,830,000

This sum need not all be expended at once, but those portions built should be in accordance with the complete plan, so far as practicable. The construction of some parts of the pumping plants, siphons, treatment plant and outlet pipes can be deferred for many years.

The area now draining to Paerdegat and the 26th Ward and Jamaica disposal plants require immediate relief. This relief will probably have to be met in part by temporary measures. It is desirable that plans for this portion of the interceptor leading to Barren Island be prepared and the work constructed at the earliest opportunity.

Eastern Jamaica Subdivision

The northern or Springfield collector starts at the intersection of the Herrick Plank road and Springfield road with a size of 2′2″x3′3″ and runs southerly through Springfield to the Rockaway turnpike, where the diameter is 4′6″. Here there will be a pumping station provided with centrifugal pumps of sufficient capacity to lift 40 million gallons per day 77 feet. The sewage of the entire subdistrict will thus be conveyed across the intervening marshes and under the proposed channel for navigation to the Jo Cos marsh disposal plant through a force main 33″ in diameter, called the Springfield force main. (See Plate III.)

The Rockaway collector will start with a diameter of 21″ near Belle harbor, where it will receive the sewage from Rockaway Park and the west from a pumping station located near Fifth and Newport avenues.

Running easterly along Rockaway boulevard, with pumping stations at Seaside, Hammels and Arverne, it will reach, with a diameter of 45″, a main pumping station at Edgemere. On the east, sewage collecting at the present Far Rockaway disposal plant will be pumped through a 12″ cast-iron force main to Mott avenue and Sheridan boulevard from which a gravity collector, increasing in size from 30 to 36 inches, will run to the Edgemere pumping station. At Channel avenue this collector receives, from a 12″ force main, the sewage collecting to the existing ejector station near Ocean and Channel avenues.

The Edgemere pumping station will be provided with centrifugal pumps of capacity to lift 30 million gallons per day 40 feet. The sewage of the entire southern part of this subdivision will thus be carried by a 30″ force main to Jo Cos marsh, crossing under the proposed channel for navigation on the way, and called the Rockaway force main.

Jo Cos marsh has been selected as a suitable location for treatment works, as it is at present waste land and centrally located with reference to the drainage area. It is at the same time a good distance from improved property. Finally, it is adjacent to the junction of Hassock creek and Broad channel, which provide as favorable conditions for dilution as are to be had at the upper end of the bay. The currents depend largely, however, upon the wind. The oscillations of the tide are not sufficient to dispose of a large volume of putrescible sewage. The plan provides for the sewage to be given thorough treatment by settling tanks, sprinkling filters and settling basins. The works will cover about 30 acres of ground by 1950.

The effluent will be conveyed by two outlet pipes 42″ in diameter, one to Hassock creek and one to Broad channel. The sludge can be used to fill marsh lands or it can be dumped at sea.

The estimated cost of construction of this system for the full estimated future population is as follows:

Collectors	40,025 lin. ft.	$511,000
Pumping stations	7	79,600
Force mains	25,725 " "	330,070
Treatment plant	......	1,061,340
Outfall pipes	3,300 " "	90,000
Contingencies	15%	310,990
Total cost		$2,383,000

Much of the cost can be deferred for an indefinite time. Such portions as are necessary to care for the sewage of Rockaway and Far Rockaway should be provided at an early date. (See Plate IV.)

Summary

Following is a summary of the more important data concerning the proposed sewerage of the Jamaica bay division:

	To Barren Island	To Jo Cos Marsh	Total
Area drained, acres	35,739	17,920	53,659
Population served	1,192,400*	223,300**	1,415,700
Mean volume of sewage—million gallons daily	166	38	204
Cost of works	$11,830,000	$2,383,000	$14,213,000
Annual charges including interest at 4½% and sinking fund for 50 years	$964,643	$239,980	$1,204,623

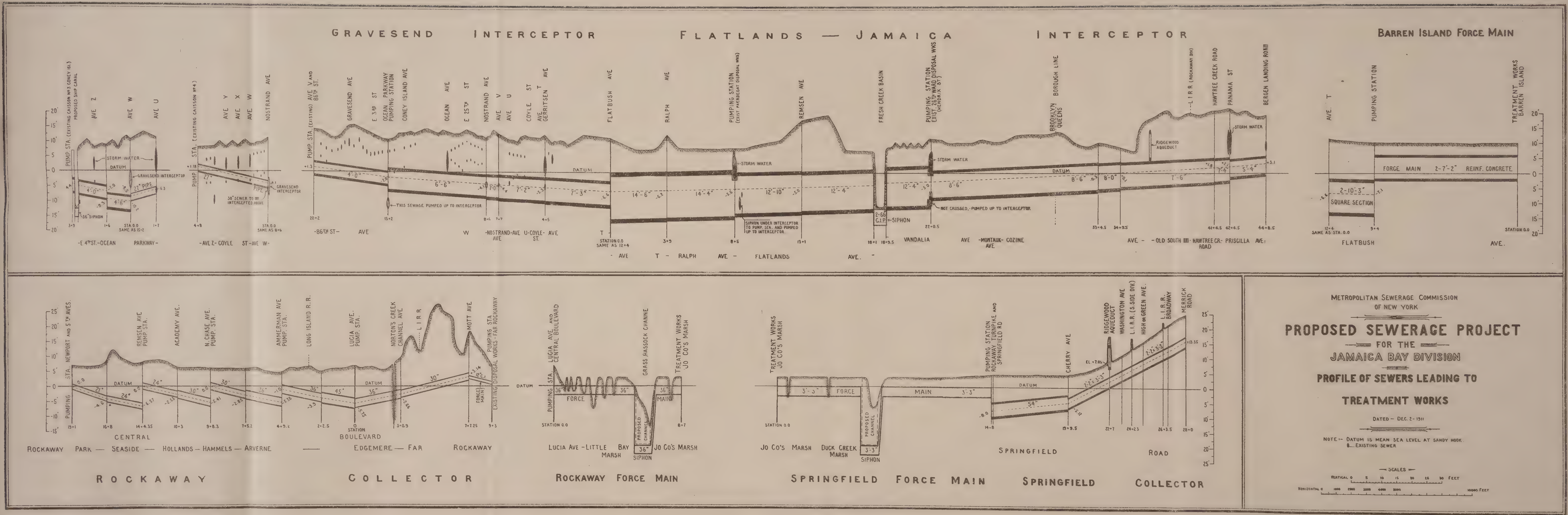
*Estimated for year 1960.
** " " " 1950.

Alternative Project for Disposal of the Sewage of the Western Jamaica Subdivision at Sea

The sewage from the Western Jamaica Subdivision may be carried to the outlet island in connection with that from portions of the Lower East River, Hudson and Bay Division (see Chapter VI, page 134). Omitting the sewage from Jamaica, on account of its distance from the main sewer, the cost of construction would amount to $4,072,000, the annual charges for maintenance and operation $80,362 and the total annual charges, including interest and sinking fund, $286,402. See Plate V.

The interceptors would then provide for 122 million gallons of sewage that might be expected from a population of 884,000 persons by the year 1960, but pumping and treatment plants would be provided only for the 47 million gallons per day that might be expected in the early future from this territory.

In this way the large outlay for a disposal plant on Barren Island, the Flatlands pumping station and the force main between the two, amounting to over $5,500,000 in the project outlined above, would be unnecessary.


GRAVESEND INTERCEPTOR
FLATLANDS — JAMAICA INTERCEPTOR
BARREN ISLAND FORCE MAIN
ROCKAWAY COLLECTOR
ROCKAWAY FORCE MAIN
SPRINGFIELD FORCE MAIN
SPRINGFIELD COLLECTOR
DATUM
STORM WATER
-E 4TH ST.-OCEAN PARKWAY-
-AVE Z- COYLE ST -AVE W-
-86TH ST- AVE W -NOSTRAND-AVE U-COYLE- AVE T - AVE T - RALPH AVE - FLATLANDS AVE. - VANDALIA AVE -MONTAUK- COZINE AVE - -OLD SOUTH RD- HAWTREE CR.- PRISCILLA AVE.
FLATBUSH AVE.
FORCE MAIN 2'-7'-2" REINF. CONCRETE
2'-10'-3" SQUARE SECTION
ROCKAWAY PARK — SEASIDE — HOLLANDS — HAMMELS — ARVERNE — EDGEMERE — FAR ROCKAWAY
CENTRAL BOULEVARD
LUCIA AVE - LITTLE BAY MARSH
JO CO'S MARSH
DUCK CREEK MARSH
SIPHON
SPRINGFIELD ROAD

METROPOLITAN SEWERAGE COMMISSION
OF NEW YORK

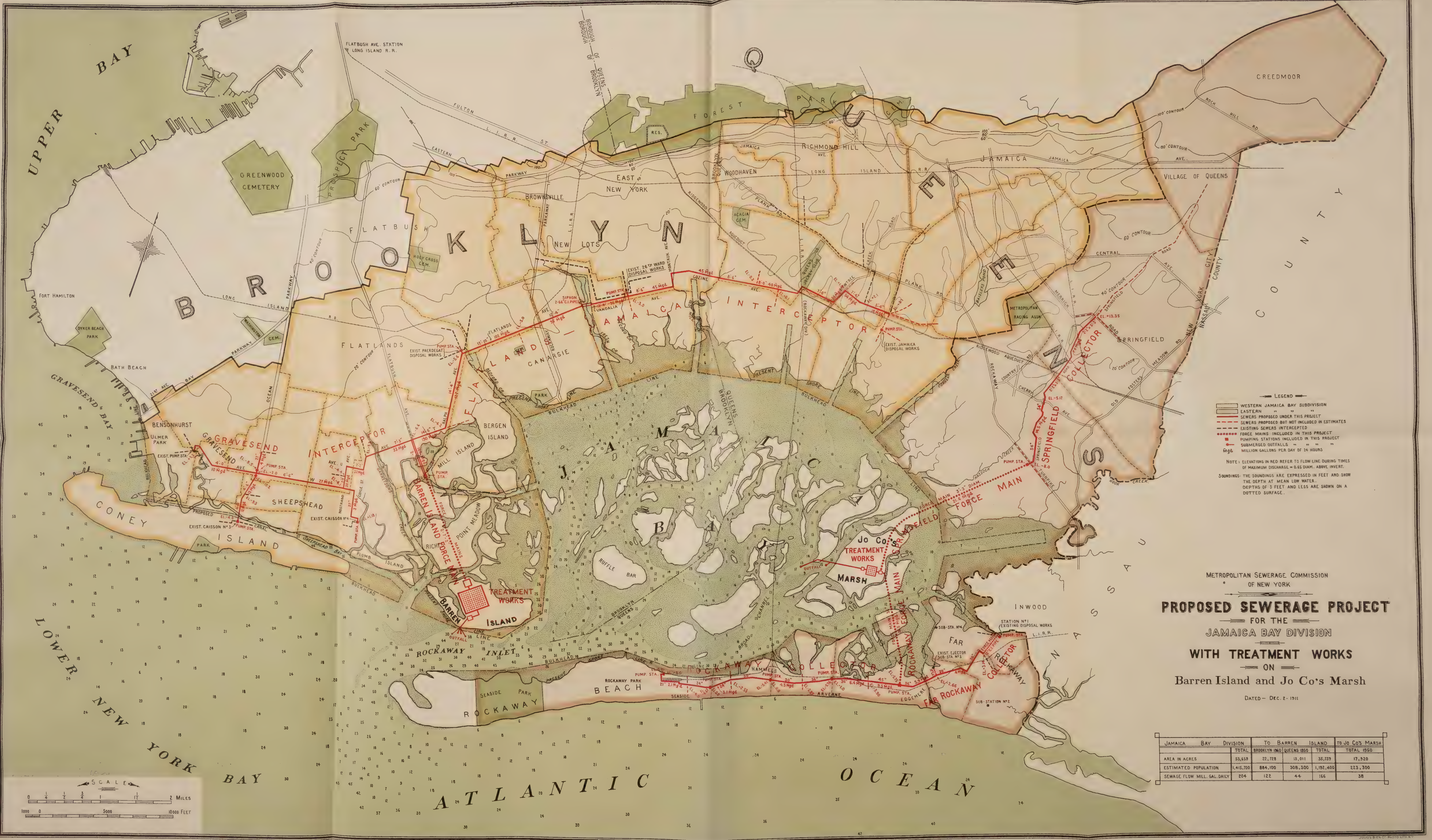
PROPOSED SEWERAGE PROJECT
FOR THE
JAMAICA BAY DIVISION

PROFILE OF SEWERS LEADING TO TREATMENT WORKS

DATED — DEC. 2 - 1911

NOTE:— DATUM IS MEAN SEA LEVEL AT SANDY HOOK.
▮ EXISTING SEWER

— SCALES —
VERTICAL 0 5 10 15 20 25 30 FEET
HORIZONTAL 0 1000 2000 3000 4000 5000 10000 FEET



Metropolitan Sewerage Commission
of New York

PROPOSED SEWERAGE PROJECT
FOR THE
JAMAICA BAY DIVISION
WITH TREATMENT WORKS
ON
Barren Island and Jo Co's Marsh

Dated — Dec. 2 - 1911

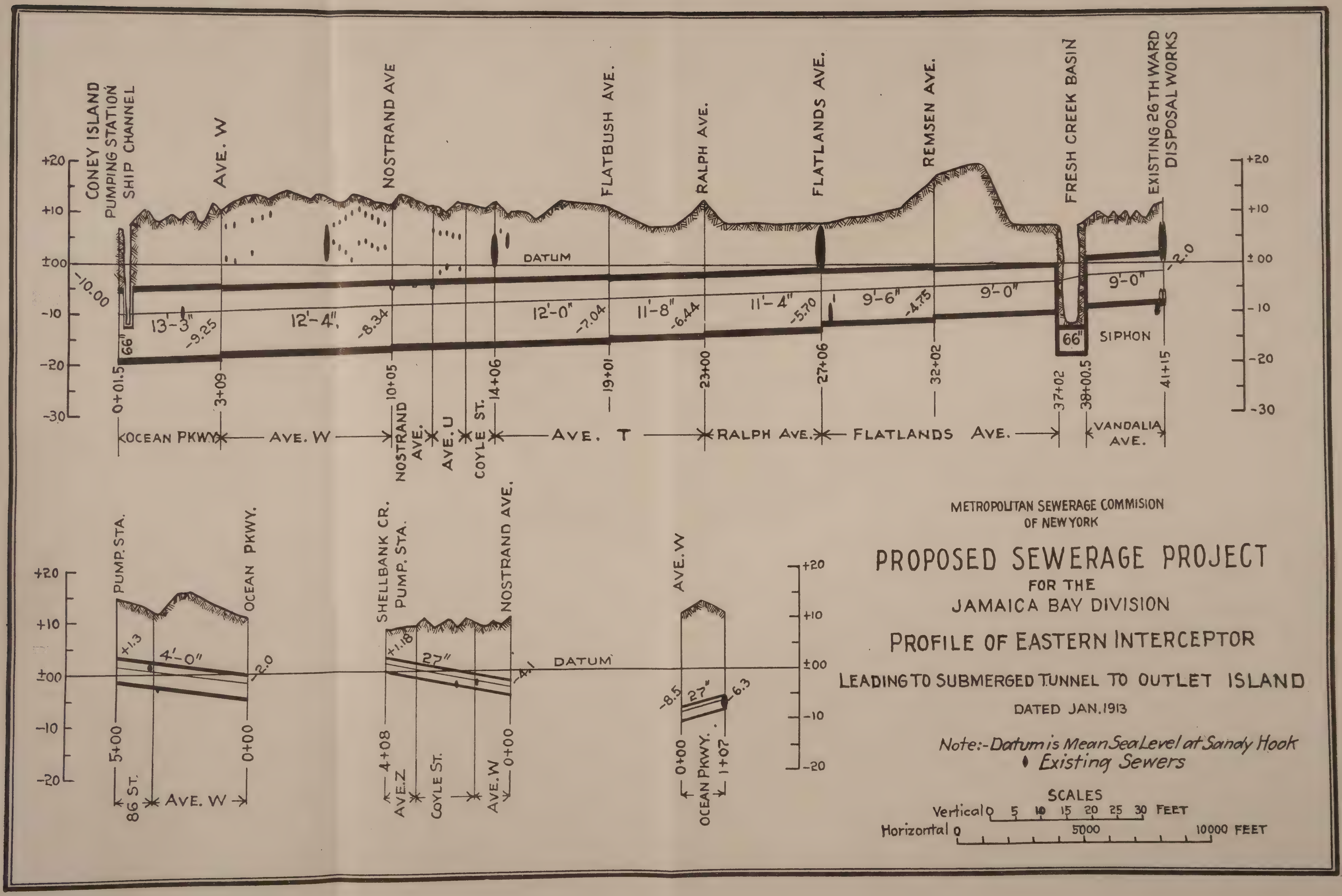
LEGEND

▭	WESTERN JAMAICA BAY SUBDIVISION
▭	EASTERN " " "
━━━	SEWERS PROPOSED UNDER THIS PROJECT
– – –	SEWERS PROPOSED BUT NOT INCLUDED IN ESTIMATES
– – –	EXISTING SEWERS INTERCEPTED
●●●●●●●	FORCE MAINS INCLUDED IN THIS PROJECT
■	PUMPING STATIONS INCLUDED IN THIS PROJECT
●—	SUBMERGED OUTFALLS " " " "
Mgd	MILLION GALLONS PER DAY OF 24 HOURS

NOTE: ELEVATIONS IN RED REFER TO FLOW LINE DURING TIMES OF MAXIMUM DISCHARGE = 0.65 DIAM. ABOVE INVERT.

SOUNDINGS: THE SOUNDINGS ARE EXPRESSED IN FEET AND SHOW THE DEPTH AT MEAN LOW WATER.
DEPTHS OF 3 FEET AND LESS ARE SHOWN ON A DOTTED SURFACE.

JAMAICA BAY DIVISION		TO BARREN ISLAND			TO JO CO'S MARSH
	TOTAL	BROOKLYN 1950	QUEENS 1950	TOTAL	TOTAL 1950
AREA IN ACRES	53,659	22,728	13,011	35,739	17,920
ESTIMATED POPULATION	1,415,700	884,100	308,300	1,192,400	223,300
SEWAGE FLOW MILL. GAL. DAILY	204	122	44	166	38



METROPOLITAN SEWERAGE COMMISION
OF NEW YORK

PROPOSED SEWERAGE PROJECT
FOR THE
JAMAICA BAY DIVISION

PROFILE OF EASTERN INTERCEPTOR
LEADING TO SUBMERGED TUNNEL TO OUTLET ISLAND

DATED JAN. 1913

Note:- Datum is Mean Sea Level at Sandy Hook
♦ Existing Sewers

SCALES
Vertical 0 5 10 15 20 25 30 FEET
Horizontal 0 5000 10000 FEET

CHAPTER VI

LOWER EAST RIVER, HUDSON AND BAY DIVISION

Briefly, the works which the Commission's studies indicate should be constructed to protect the waters of the Lower East river, Hudson and Bay Division consist of intercepting sewers to collect the sewage, screening plants to remove the coarser solids, and submerged outlets to discharge the effluent into the main tidal channels at a distance from shore. Should this form of treatment prove insufficient for the Lower East River Section, it will be desirable to remove a large part of the sewage tributary to the Lower East river by means of a tunnel discharging at an artificial island at sea about three miles off the Coney Island shore. If the sewage is to be carried to sea, Dortmund tanks should be constructed upon the island and the sewage subjected to sedimentation for a period of about two hours. After this short and inoffensive treatment the sewage can be discharged into the ocean with confidence that the putrescible matters will be promptly rendered inert.

The Commission's studies of the Lower East river situation have been examined critically by five eminent sanitary experts whose reports will be found in Part III, Chap. I, page 155, of this report.

Boundaries and Topographical Features

The territory in the Lower East river, Hudson and Bay Division lies on both sides of the Lower East river, the west side of Manhattan and the east side of Upper New York bay. It extends from the extreme northwestern boundary of the city to below the Narrows.

It contains the largest population, and the most densely settled sections of any of the four divisions into which the Commission has divided New York for the purpose of planning the main drainage and sewage disposal works which will be required. Within it lies the major part of the Boroughs of Manhattan and Brooklyn, which were separate cities until 1898.

This division is bounded on the east by a line which begins at Bensonhurst on Gravesend bay, runs in an irregular course northeasterly to Forest Park, in the Borough of Queens, and thence northwesterly to the East river near the mouth of the Harlem river. All of that part of Brooklyn and that part of Queens which lie to the west of this boundary line are included in the division. Crossing the East river the boundary enters upon Manhattan Island at East Eighty-second Street, proceeds northwesterly to Central Park West, which it crosses at Ninety-first Street, and thence follows an irregular northerly direction along the height of land to the Harlem river at Spuyten Duyvil. That part of Manhattan, which lies to the south and west of the boundary so described, lies in this division. A small part of the division borders on the Hudson between Spuyten Duyvil and Yonkers. The western boundary of the division is formed by the Hudson river, Upper New York bay, the Narrows and a part of Gravesend bay.

In the northern and southern parts of this division the topography is favorable to drainage, but there are large areas near the center which are so low and flat that the construction of sewers with sufficient grades to insure self-cleansing velocities and outfalls so situated as to provide for a free discharge at all stages of tide is impossible.*

Made Land. Many of the sewers in Manhattan feel the effect of the rising and falling tide for a considerable distance from the shores, in some instances, for over one mile. The worst cases of this kind are usually ascribable to the inadequate filling of low-lying or submerged areas such as the beds of creeks and the once marshy shores of water courses. A remarkably regular shore line, made by filling in Manhattan, is shown on modern maps.

TABLE XIV

ACRES OF FILLED LAND IN THIS DIVISION

Borough	Acres
Manhattan	1,140
Brooklyn	1,520
Queens	460
Total	3,120

The filling has been largely, but not entirely, done along the water front. From 82nd Street on the Hudson river, southward, to the Battery, and thence northward along the Lower East river to 33rd Street, Manhattan, the marginal street is entirely on made land, the total length of shore so recovered being ten and one-half miles. In many instances the made land extends some blocks back from the river front and in the neighborhood of Canal Street, Manhattan, it runs across the island, a distance of nearly two miles.

On the Brooklyn shore, the made land extends from a point north of Newtown creek to near 45th Street, South Brooklyn, a distance of eight miles. The Brooklyn Navy Yard is entirely on made land. A large area in the neighborhood of Red Hook and Gowanus canal, Brooklyn, has been reclaimed by filling.

The growth of made land has been gradual. It has increased with the increasing size of the city. The chief object in filling in the low-lying places has been to eliminate swamps and marshes and make the area of ground available for trade and commerce more extensive than originally existed. At the same time the filling has proved a convenient means of disposing of refuse.

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*For data as to topography, residence and business sections, approximate land values, and populations, see Plate IX, following page 138.

If cellar earth and other suitable refuse material were utilized in filling in the swamps and meadow lands which exist in the outlying parts of New York City, the shore lines in parts of the harbor estuaries which are now seriously polluted would soon be straightened and the water would be more easily kept clean than under the existing circumstances.

To facilitate the filling in of the low-lying shores, the Harbor Line Board, composed of engineer officers of the U. S. Army, which has charge of maintaining the navigable channels of the harbor, has established lines for solid filling. These lines extend throughout the harbor and give a good idea of the plans to which future operations of filling will probably conform.

The land which lies in this division at elevations within twenty feet of mean sea level includes all the filled land and also some additional areas, mostly in Brooklyn and Long Island City. A broad belt runs from the head of Newtown creek to the vicinity of the Brooklyn Navy Yard. The total area below twenty feet elevation in this division is about 3.3 square miles in Manhattan; 6.5 square miles in Brooklyn and 2.9 square miles in Long Island City. Seventy-three per cent. of all the land in this division is of more than twenty feet elevation above mean tide. In Manhattan the high land lies for the most part near the center of the island. The highest point is somewhat above 200 feet, and is situated north of Dyckman Street. There is no point above sixty feet elevation further south than 33rd Street.

In Brooklyn the land which lies at an elevation above sixty feet, exists chiefly in the eastern part of the division, where a well recognized ridge runs in a northeasterly direction from the vicinity of the Narrows. Elevations of 100 feet or more frequently occur on this ridge.

Tidal Range. The difference between mean sea level and mean high water is one-half the mean tidal range as given in Table XV.

TABLE XV

RANGE OF TIDE IN NEW YORK HARBOR

	Mean	Spring
Lower bay, Sandy Hook	4.7	5.6
Narrows, Fort Hamilton	4.6	5.6
Upper bay, Governor's Island	4.4	5.3
Hudson river, Spuyten Duyvil	4.0	4.8
East river, Hallett's Point (Hell Gate)	5.5	6.6
East river, Throg's Neck	7.2	8.5
Harlem river, High Bridge	6.0	7.2
Kill van Kull, Shooter's Island	4.6	5.5
Newark bay, Passaic Light	4.7	5.7
Passaic river, Newark	5.0	6.0

Geology. The superficial geological formation of this division is recent except for a small, low-lying area of stratified drift in and near 125th Street. The surface of Manhattan island as far south as 23rd Street is composed chiefly of mica schist rock. South of 23rd Street the rock disappears, and stratified drift predominates.

In the Brooklyn part of this division drift exists on each side of the central ridge, the ridge itself exhibiting the features of a terminal moraine with till on the western slope. Swamp and marsh lands exist to a limited extent, and then only in that part of Queens which lies in this division.

Value of Land. The most valuable land in this division lies in the central and southern parts of Manhattan. It is a peculiar fact that whether for business or residence purpose, the most costly land lies along the center of the island. At the southern extremity is the financial district. North of this is the City Hall with the central post-office, numerous newspaper offices, the principal law courts and municipal administrative headquarters. Next above follows the wholesale dry goods center, then the region of retail shops, hotels and theaters and finally areas of high-class private residences and apartment houses which extend to the northern limits of this division. From this central zone east and west to the river fronts lie areas occupied by factories and residences, the latter ranging from modest dwellings to congested tenements.

In Brooklyn the water front is chiefly occupied by large factories and warehouses. The most crowded residence district and the center of financial administrative activity lies in that part of the borough which is opposite the southern end of Manhattan Island.

The Existing Sewers—Their Outfalls and Resulting Nuisances

Practically the whole of this division is sewered on the combined principle of sewerage.

In addition to the sewage which comes from the storm water of the streets and from the interior of the houses, the sewers of Manhattan and Brooklyn are required to carry away the water which falls upon the roofs, yards and courts of the buildings. The connections are trapped in order that the air from the sewers shall not enter the houses. The plumbing of the houses is ventilated by extending the soil pipes to the roofs.

In many cases, especially in Manhattan where the cellars of large buildings are deep, it is often necessary to pump the sewage into the street sewers. This is done at private expense.

Relief Sewers. In most of Manhattan the sewers, which are large and short, have generally proved adequate to the requirements of the growing population; but in Brooklyn much trouble has been experienced from the insufficient provisions which were early made for drainage. The first sewers were built when the populations which they were required to serve were small and scattered, and when a comprehensive system of sewers was built between 1850 and 1860, the rainfall data were inadequate to permit designers fully to understand the requirements. With the increasing population the original sewers have been supplemented by large and expensive relief sewers, and these in turn have had to be assisted in some cases by the construction of intercepting sewers for the collection and removal of storm water.

The sewers of Manhattan and Brooklyn are of many shapes and sizes. Among the older sewers of Brooklyn are many storm drains whose courses are not known. The older sewers are generally circular in shape, and when over twenty-four inches in diameter are of brick or concrete. Clay and cement pipe have been extensively used for the smaller sizes. Since 1907 the principles of design and construction have been much improved in Brooklyn.

Most of the sewer outlets on the Manhattan shores are between two and five feet in diameter, but there are some which have a section equivalent to a circle having a diameter of ten feet and more. The outlets on the Brooklyn shore are somewhat less numerous and some are larger than the largest of Manhattan, having a section equal to a circle with a diameter of fifteen feet.

Many of the sewers of Manhattan were built many years ago. They represent various periods of growth due to the introduction of public water supplies and other causes and have been extensively reconstructed and repaired within recent years.

Throughout this division the sewers are provided with catch basins at the street corners which were intended to convey the storm water from the gutters and protect the sewers from grit and other solid substances.

Ventilation. It was intended that the sewers throughout this division should be ventilated through perforations in the manhole covers located at frequent intervals in the street. In most parts, notably in the older sections near the water front, the ventilation is defective, partly as a result of the settlement of the sewers, the entrance of tide water and the submergence of the outlets. Nuisances frequently result where steam and hot water are discharged into the sewers, since hot vapors rise and issue through the manhole covers disseminating odors of cooked sewage.

Outlets. The outfalls of the sewers of this division, as elsewhere in the metropolitan district, are located at the bulkhead or shore line or, frequently in Manhattan, near the outer ends of the docks and piers.

The submergence of the sewer outfalls, as at present, and the rising of the tide drive the foul air into the streets and produce coatings of grease and solids upon the sides of the sewers, and this interferes with the flow of sewage. So much deposit is produced in some of the sewers that a cleaning gang, working continuously, can make no appreciable reduction in the depth of the deposit. Congealed grease has been found to measure as much as a foot in thickness in some of the sewers of Manhattan.

Physical Condition. Inspections of the sewers made by the Metropolitan Sewerage Commission with the co-operation of the Bureau of Sewers of the Borough President of Manhattan have revealed many examples of distorted shapes, worn out inverts, sunken arches, and cracks due to settlement. In many places irregular holes had been broken through sewers in making connections, and the holes never properly repaired. It was impossible to enter some of the sewers for inspection owing to steam and hot water escaping from neighboring buildings. Other sewers could not be entered on account of the presence of illuminating gas in such quantities as to endanger health. In other areas, lanterns could not be carried into the sewers on account of gasoline vapor, presumably from automobile garages or other establishments using this explosive compound.

In Manhattan the sewers are inspected and cleaned only on complaint. The sewers are not flushed, but are cleaned by hand. Street sweepings are frequently pushed into the catch basins against orders in Manhattan and Brooklyn.

Catch Basins. The effect of the catch basins in removing solids from the sewage is comparatively slight. They soon become filled with grit and other solid matters. To be of material use, they should be cleaned after nearly every storm. This is not done. The records for the year 1909 show an average of one cleaning for each catch basin in Manhattan every 5.3 months. This does not mean that all the 6,348 catch basins in the borough were cleaned. Some were cleaned out at comparatively frequent intervals and others were not cleaned at all.

In the year 1907 the catch basins in Brooklyn were cleaned on an average about 2½ times a year and the quantity of deposits removed aggregated 35,272 cu. yds. The cost of removing this material was $1.12 per cubic yard. The incompleteness and great cost of removing solid matter from sewage by the use of catch basins can be readily understood from these figures.

Large quantities of solid matters which pass the catch basins are deposited in the sewers themselves and are eventually removed by hand, washed out by the flood water of storms, or carried away through the alternate choking and flushing action which is produced by the rising and falling tide.

About 400,000 cubic yards of deposits are dredged each year from the slips and docks of that part of Manhattan which lies in this division by the Department of Docks and Ferries and large quantities are also dredged by private enterprise and from the Brooklyn shores. It is generally conceded that this solid material comes chiefly from the sewage. The water from which the deposits are taken is often black and offensive and gases of putrefaction rise in innumerable bubbles from the deposits at the bottom. During flood currents the sewage matters are driven back into the slips and in this quiet water some of the solid matters are deposited. On the outgoing tide grease and excreta are left adhering to the dock walls and piers. In the immediate vicinity of the outfalls the water is discolored and objectionable in appearance and odor. In some cases many acres are rendered turbid by the sewage.

Nuisances. Extensive nuisances occur in this division at various points along the Brooklyn and Manhattan shores. Gowanus canal, Wallabout bay, Newtown creek, the foot of Broad Street, Oliver Street and Fourteenth Street are the most conspicuous. The bodies of water affected are actually large, although small in comparison with the great areas of the main divisions of the harbor. The condition of Gowanus canal, into which a 15-foot relief sewer as well as some eight other sewers ranging from 1½ to 6½ feet in diameter discharge, has been notorious for years. The water is black and foul-smelling at all times and the sides of the piers, bulkheads and masonry structures are coated with deposits. As a means of improving this canal, the Borough of Brooklyn has constructed a flushing tunnel which leads from the head of the canal to an outlet in the Upper bay. Pumps force the water from the head of the canal through the tunnel, which is 6,270 feet long and 12 feet in diameter. The outlet is about 2 feet below low tide and is situated close to the shore between two long piers. The water in the vicinity of the outlet is strongly discolored when the pumps are in operation, the discharge from the tunnel being visible at times in the water after it has been carried by the tide for a distance of more than a mile.

Wallabout bay in the Lower East river is polluted by a 9-foot sewer which discharges at the bulkhead line. The point of discharge is so protected from the tidal currents that a satisfactory dispersion of the sewage cannot take place. The bay is exceedingly offensive at all stages of tide, the bottom being covered with putrefying sewage sludge and the top with sewage apparently in an undiluted state. These objectionable conditions are in front of the New York Navy Yard.

Newtown creek, which empties into the Lower East river from a low-lying manufacturing district north of Brooklyn, is an offensive body of water. It supports a heavy traffic. Considerable quantities of manufacturing wastes are discharged into the creek from warehouses, elevators and factories, which line both banks. Some sewage empties into it, although the further pollution of this stream is prohibited by law. A 15-foot sewer, constructed through the joint action of the Boroughs of Brooklyn and Queens, empties into the head of Newtown creek and although this sewer was intended to accommodate storm water only, the dry-weather flow being diverted, considerable pollution is ascribable to it.

The condition of the waters of the Lower East river as regards oxygen is described in this report, Part IV, Chap. VI, page 641, and Part III, Chap. I, page 184.

There are no figures available to show the total cost of the sewers which exist in this division. It has been estimated that those of Manhattan exceeded $26,000,000, and it is believed that those of Brooklyn have cost about an equal sum. There are about 522 miles of sewers in Manhattan and about 814 miles of sewers in Brooklyn.

Possibility That the Sewers of Manhattan Will Have To Be Rebuilt.

It has seemed to those charged with the duty of maintaining the sewers of Manhattan, as well as to consulting engineers who have been called upon to examine into the subject, that it would eventually be necessary to reconstruct a large part of the existing sewers of Manhattan.

The chief reason for reconstruction lies in the need of repairs and the harm done to the sewers from the building of underground structures of various kinds, as, for example, passenger subways, conduits for electric light, telephone and telegraph and pipes for water, gas, steam and pneumatic mail service. As the city is entering upon extensive subway construction, it may be well to consider whether the interferences which now exist or are to be expected will not cause so much expense and make the sanitary removal of the sewage so difficult that a reconstruction of the sewers will be a practical necessity. If the sewers are to be rebuilt, this fact should be known and preparations for it made at once so that such saving as can be effected in the cost of temporary alterations can be accomplished.

Right of Way of Sewers. Of all the many structures beneath the city's streets, it is most important that the sewers should have the right of way. Unlike pipes for water, gas or electricity, which operate under pressure, sewers, whose flow is due alone to gravity, must be laid to proper grade and alignment or they will not operate properly.

To be self-cleansing, sewers should maintain a certain velocity of flow and any reduction in the grade which checks the velocity will lead to deposits. Short turns and bends and changes in the cross-section also alter the flow and interfere with the proper function of the sewer.

When it is remembered that sewerage systems should be well designed and constructed; that they are built under the ground in a manner which is intended to be permanent and durable; that they cannot be altered in size, shape, grade or location without harmful consequences; that their function is to carry off promptly and completely the most offensive and dangerous wastes of a city, the claim of the sewerage system for right of way beneath the streets appears to be fully justified. That this claim has not been respected is a regrettable fact. In defiance of the officials charged with the duty of maintaining the sewers, they have been moved from place to place, pierced and damaged in many ways. Instead of being used for the purposes for which they were built, the sewers have been abused by the discharge into them of harmful manufacturing wastes, hot water and steam and been rendered dangerous for inspection by the illegal emptying of gasoline and other inflammable compounds.

The structures which interfere with the sewers are located at depths which range from that of the shallow conduits which carry the current for the surface railways to that of the passenger subways. The passenger subways form a serious obstruction. They are situated as close to the surface of the street as practicable in order to facilitate entrance and exit and they require over 20 feet of depth. For the most part, the subways, like the water, gas and other large mains run longitudinally through the island and the sewers in seeking their outlets to the rivers run perpendicularly to them.

Interference from Subways. The first subway for passengers was built on a line which divided the sewerage systems of Manhattan into approximately two equal groups, the subway following along the axis of the island for most of its length. The interference with the sewers was, in this case, as slight as possible, it being feasible to cause the sewage to flow in many instances with but little alteration of the sewers to a convenient point of discharge to one of the nearby rivers on the east or west side of the island. But other subways which have been designed will run in lines nearly parallel to the first and will divide the sewers further. There will be no easy readjustment possible, as in the first case, for there will be a central area which will be blocked off by the subways from the river on either side. In order to carry the sewage past these new subways, it will be necessary to make extensive reconstructions. It will be necessary to collect the sewage to more or less suitable points in the areas between the subway lines and then conduct it by siphons beneath the subway structure to points from which it can flow away by gravity. The alignment and grade of the sewers will, in many cases, be seriously interfered with. The siphons, which should be capable of being emptied, inspected, repaired and cleaned, will be costly to build and, when of considerable depth, difficult to maintain. Sewage which now flows directly across the island will have to be diverted so as to run for considerable distances longitudinally, with the result that there will be a tendency to loss of velocity and formation of deposits in the drains.

Need of Repairs. An important argument for reconstructing the sewers of Manhattan lies in the need for repairs. Inspections made by the Metropolitan Sewerage Commission have shown that some of the sewers, and especially the older ones, are in dangerous condition. Of 246 inspections, 38, or one-sixth, showed places where the sewers will have to be rebuilt within a few years on account of defective brick work alone. These locations exist along the whole length of the island. Of the 522 miles of existing sewers in Manhattan, 55 miles are seriously out of repair. To repair these, would involve an outlay which could more profitably be spent on new construction.

Separate vs. Combined System. If the sewers were reconstructed, it is the opinion of many engineers that they should be built upon the separate system. Drains for storm water should be laid close to the surface of the streets and should be large and have ample grades to carry off much solid matter. When street washing, which is rapidly coming into favor, becomes general in the city, the quantity of grit and other solids to be removed by the sewers will increase. To a great extent the storm sewers should be made to carry off snow. Storm sewers should be built without catch basins at the street corners and should lead to central points where grit and other heavy materials can be removed before the sewage is discharged into the harbor. The elimination of the 14,000 catch basins which now exist would be desirable.

Sewers for house drainage should be laid so far beneath the surface of the streets as to permit the sewage to flow into them by gravity. They should be sufficiently deep to pass clear of all other subterranean structures. The comparatively small size which the sewers for house sewage would require would permit them to be located, even in congested streets, so as to give good alignment and grade. The sewage would thus be more promptly carried away than under present circumstances. In general these sewers would run perpendicular to the subways, crossing under them and delivering at suitable places into interceptors for conveyance to sewage disposal works or pumping stations.

Objections Against Reconstruction. The objections to the reconstruction of the sewers of Manhattan lie in the expense and inconvenience which the reconstruction would directly and indirectly entail upon the public. Almost all the streets of the city would require to be opened and the large quantities of earth and materials of construction would have to be handled without stopping vehicular traffic where the alterations were going on. The plumbing of over 150,000 houses would require to be altered so that the proper sewer connections could be made.

It is not clear how the storm water sewers, which should be laid close beneath the surface of the streets could escape the underground trolley conduits above, and the passenger subways beneath, in the longitudinal highways. There should be no siphons on these storm water drains.

Quantity and Composition of the Sewage

The quantity of the sewage produced in this division can be estimated from a knowledge of the water consumed and the rainfall. But few of the sewers have been gauged and exact measurements of their flow are not available. As compared with many cities, especially those of Europe, the volume of sewage is large and its composition variable. It is, for the most part, remarkably fresh when discharged, owing to the short distance, and consequently brief time, consumed in passing from the houses to the outfalls.

The conditions of residence and manufacture are various in this division and the sewage which reaches the outfalls is correspondingly variable. The quantity produced is different at different hours of the day and night; and it is not the same at all seasons of year. Owing to the fact that most of the sewers for some distance from the shores of the harbor are choked with tidal water, the sewage is often mixed with salt water before it is discharged. In some cases the sewage is warm with the waste steam and hot water which is discharged from large office buildings, hotels and manufacturing establishments.

At times of rain much polluting water is washed from the streets. The quantity of this material is doubtless increasing, due to the more extended practice of washing the streets with water. After snow storms, snow is, to some extent, discharged into the sewers and with it more or less solid matter, which was either present on the pavements before the beginning of the storm or is thrown out after the snow begins to fall.

For the composition of sewage, and for the quantities of sewage materials which are tributary to the various divisions, see Part IV, Chap. III, page 499. For the volumes of sewage tributary to the various divisions, see Part II, Chap. II, page 46.

Possible Methods of Sewage Treatment

Early studies made by this Commission indicated that, excluding from the harbor as much sewage matter as practicable from those parts of Queens, Richmond, Brooklyn and the Bronx which are tributary to the Upper East river and Upper and Lower New York bays by the employment of local purification works, the water of the inner harbor would be able to assimilate the sewage from those parts of Manhattan and Brooklyn which were closely built up and where sites could not readily be obtained for the construction of purification works of high efficiency. In this belief plans were begun for collecting the sewage of the Bronx, Queens and Richmond and gathering it to a number of conveniently located central points for treatment.

Two immediate objects were to be attained by these plans. First, the harbor water in those divisions where the works were located was to be kept clean, and, second, the water was to be protected to such an extent as to insure to the inner harbor the largest assimilative capacity practicable.

As the plans progressed, it became evident that a high degree of purification could not be obtained for as much of the sewage as had been expected. To remove a large proportion of the putrescible material from sewage requires works which could not always be situated where engineering considerations alone would have placed them. In such cases land must be procurable at a price which does not unduly increase the first cost of the project. Of equal importance, it is necessary to locate such works in positions where the odors produced will not injure property to such an extent as to give owners of surrounding land valid claims against the city for damages.

Odors from Efficient Processes. It is needless to deny that all processes of sewage purification cause smells. The fact should plainly be faced that in the removal the ingredients of sewage which are capable of causing the water into which the sewage is discharged to become offensive, objectionable odors may be produced at the works. The danger of nuisance depends partly upon the degree of thoroughness with which the impurities are removed and partly upon the likelihood that the property holders in the vicinity will find the odors seriously objectionable. There are localities in the City of New York and vicinity where objectionable odors are continually produced by manufacturing establishments with little or no complaint from property holders. But these situations are not usually well placed for sewage disposal plants, and it is doubtful if the city would be justified in adding to these odors even if it became otherwise desirable to construct sewage works there. Manufacturing plants which are objectionable, such as slaughter-houses, bone-boiling establishments and fertilizer factories, usually have to move further and further away, as the cities in which they are located grow. Nuisances of this kind become increasingly objectionable as time proceeds, for more and more people become affected and the public becomes increasingly fastidious.

Such strong and offensive odors as are produced by so-called offensive trades are not likely to be produced by sewage works, but the difference is sometimes not great, and the erroneous belief that sewage odors are in some way connected with disease, if not actually a cause of it, adds greatly to the objectionableness of sewage purification plants in any locality.

A convenient and economical location for sewage works is hampered by the uncertainty that they will be permanent. Unlike some manufacturing plants, they cannot well be moved in case they produce a nuisance. If they are objectionable at first, they are likely to become more so with the passage of time. Owing to the protest with which a proposal to build a municipal plant for the thorough treatment of sewage probably would be received in almost any part of New York City, this Commission has felt compelled to confine its plans largely to works of the simplest character or carry the sewage to a distant point for disposal.

In the selection of sites, considerable difficulty has been experienced because of the changing character of many localities. Few parts of New York are permanently constructed. Solidly built-up sections are constantly changing from residence to business occupancy. Suburban districts are rapidly becoming urban, and rural territory is being converted to suburban uses. Each change increases the value of the land. The most rapid developments, and the most uncertain, are sometimes in the very localities where it would be most convenient to build sewage disposal works. Here unimproved property, even farm land, is not infrequently held at a high valuation in the expectation that a strong demand for real estate may set in at any time.

Owing to the facts here mentioned, this Commission has not found it feasible to design works which would purify the sewage tributary from the outlying territory to a high degree, and the water which will reach the inner harbor will consequently not have as great a capacity for assimilating sewage as theoretically it should possess.

What is here said as to the nature of the works which it has been feasible to design for Queens, Richmond and the Bronx applies with greater force to the Lower East River, Hudson and Bay Division. The aggregate volume of sewage produced in this division is now great, and thirty years hence will be about double what it is to-day. Such treatment as it is practicable to accomplish within the territory where this sewage is produced will remove only a small proportion of the ingredients which are capable of reducing the amount of oxygen in the water into which the effluent is discharged. Sprinkling filters, contact beds, sedimentation basins and chemical precipitation plants cannot be considered for want of land and because of the odors which such works would produce.

The forms of treatment which could be best employed on the shores of Manhattan and Brooklyn would be such as could be carried on with grit chambers and screens. The report of Mr. Datesman (see Part III, Chap. I, pages 259-263) contains a discussion of this subject, particularly as relates to sedimentation basins in the built-up parts of Manhattan and Brooklyn. Beside being compact, they produce little odor; they can be located partly below ground; they require no extra pumping; they are comparatively inexpensive to operate; they can be employed without highly skilful supervision, and it is practicable to have many plants of moderate capacity. Against them is chiefly the criticism that they remove only the largest particles of sewage matter and leave the dissolved organic matter and finely divided putrescible materials to pass to the harbor. Notwithstanding this fact, they would serve usefully in attaining the standard of cleanness which the Metropolitan Sewerage Commission has proposed for the water.

able for treating the sewage of Manhattan and Brooklyn locally, it is desirable to con-

Inasmuch as grit chambers and screens afford the best practicable means avail-
sider how such works would be constructed, how many plants would be required, about where they should be built, what they might cost and how much improvement they would accomplish. In studying these questions, two chief considerations have appeared to be important. First, the outlets from the works should be so built that the treated sewage will be promptly and thoroughly diffused, and second, the plants should be so located as to permit the sewage to be collected to them without unnecessary difficulty or expense.

Submerged Outfalls. Owing to the incompleteness of the purification, and the desirability of complying with the Standard of Cleanness,* as relates to discoloration and turbidity, it would be necessary to discharge the effluent from the plants in such a way as to produce the most immediate disappearance of the sewage which is possible. For this purpose, it is desirable that the outfalls should be near or upon the bottom and be so located that ample and strong currents will sweep by them.

Locations for Outlets. Bearing in mind the difficulties of construction and maintenance, as well as the advantages of carefully selected places, a number of points have been chosen along the shores of Manhattan and Brooklyn where the sewage, after treatment, could with the greatest advantage be discharged.

The facility with which the sewage could be collected to suitable points for treatment was taken carefully into consideration in selecting the points of outfall. It was thought desirable that the sewage should require the least amount of pumping possible; that the plants should not have to be placed too far below tide level and that the greatest possible normal flow of sewage should be gathered to each plant.

Considerable care has been taken in the designs to make an economical use of land, to provide for adequate inspection and repair, not only of the apparatus, but of the structure itself, to insure light and ventilation and to facilitate the cleaning of the basins and screens and the removal of the impurities from the plant. Numerous forms of grit chambers have been designed and studied. Every form of screen which the experience of other cities had proved reliable and efficient has been considered.

Plan Recommended for the Disposal of the Sewage of this Division.

Investigation having shown that it will be impossible permanently to discharge all the sewage into the water in the vicinity of the territory where it is produced, after such purification as is practicable, it becomes necessary to consider where it can be taken and what can be done with it.

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*Report of Metropolitan Sewerage Commission of New York, August, 1912, page 70. For modification of Standard, see Part III, Chapter I, page 218.

Amount of Sewage to be Taken Away. It will not be worth while to take a small amount of sewage from the inner harbor. To accomplish much benefit, the volume will have to be large both actually and in relation to the total quantity produced in this division. If possible, it should be taken from a part of the harbor which needs relief both on its own account and because of its influence on adjoining sections. As far as practicable, the sewage should be collected from a region of dense population in order that the length of the sewers shall be no greater than necessary. For the same reason the distance from the central point of collection to the point of disposal should be as short as possible.

This report shows that the greatest burden of pollution which is placed upon any large portion of the harbor is discharged from Manhattan and Brooklyn into the Lower East river. Here within a distance of 4 miles, about 283,000,000 gallons of sewage are discharged every 24 hours from about 50 outlets located along the crowded shores. Not only is the volume of sewage large, but, as shown elsewhere in this report, the waters are peculiarly unsuited to receive it. See Part IV, Chap. III, page 496, and Chap. VI, page 641.

If most of this polluting material can be removed, the waters in the immediate vicinity will be improved and the excessive burden of pollution now put upon the whole inner harbor will be relieved. An improvement of the waters of the Lower East river is desirable for the help it will give in disposing of the sewage which, in accordance with the Commission's plans already announced, will be brought to Wards Island.* At Wards Island the large quantity of sewage which will be brought from the Harlem river will be passed through settling tanks and discharged into the deep waters of Hell Gate, and reliance must be placed upon the digestive capacity of the waters to oxidize the liquid organic matters.

If 200,000,000 gallons of sewage per day can be kept out of the Lower East river, the ratio of sewage to water in that section will improve sufficiently to meet all requirements of this Commission's standard of cleanness for the present. The ratios of water to sewage which will exist in the Lower East river are given in Table XVI.

TABLE XVI

RATIOS OF SEWAGE TO WATER IN THE LOWER EAST RIVER, IF 200,000,000 GALLONS OF SEWAGE PER DAY ARE KEPT OUT OF THIS WATER.

Year	Sewage to water at Low Tide.	Sewage to Tidal Prism.	Sewage to Net Ebb Flow.
1910	1 to 1090	1 to 204	1 to 30
1940	1 to 178	1 to 33	1 to 5.6

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*See Chap. III, page 65.

The Plan Recommended. The plan recommended by the Commission contemplates the collection of the Manhattan sewage tributary to the East river below 26th Street at Corlears Hook, and that part of the sewage of Brooklyn which is tributary to the East river from Classon Avenue to Newtown Creek at South 5th Street. At Corlears Hook and South 5th Street the sewage will pass through grit chambers and fine screens and will be discharged into the East river through multiple submerged outlets. This is the first stage in the larger project of taking the sewage of the Lower East river section directly to the sea, which is the plan the Commission recommends for ultimate construction.

Advantages of Disposal at Sea. In accordance with the ultimate plan proposed for the Lower East river section, the sewage will be tributary to a general central station, to which point will be gathered such part of the sewage as needs to be carried to a distance. Pumps will be located at the central station and from it a main will run directly to an outfall island to be built about 3 miles from land on a sandy reef. This reef is one of a series of shallow areas, interspersed with channels, which once formed the bar to New York harbor. It lies slightly to the west of an imaginary line between Sandy Hook and Rockaway Point. The outfall will be about 13 miles from the New York City Hall, 6 miles from the Narrows, over 4 miles from Sandy Hook and about 3 miles from Coney Island. The point selected for this island is shown in the Frontispiece.

As much sewage as it is necessary to carry to a distance from the Lower East river, Hudson and Bay Division can be taken to the island for disposal. As time proceeds and the quantity of sewage increases, the main sewer can be duplicated and the provisions for treating and discharging the sewage at the island can be enlarged.

A large part of the sewage of this division is now discharged into the waters of the Lower East river. If this sewage is taken away for disposal, it will for some time, at least, be possible to discharge the sewage from the rest of this division with no other treatment than screening and passage through grit chambers. The water of the Hudson will be capable of assimilating the sewage produced on the west side of Manhattan Island and the water of the Upper bay could take the sewage produced along the Brooklyn water front from Governor's Island southward.

All the sewage from this division, except that part which is taken away, should be passed through grit chambers and screens and the dry-weather flow discharged through submerged outlets. In course of time, if the quantity of sewage from this division, as well as from that part of the Upper East river and Harlem Division which would be concentrated at Wards Island, increases to such an extent as again to place an excessive burden upon the waters of the East river, the sewers can be extended and finally the Wards Island works can be connected with a main sewer to the artificial island for disposal.

The plan of relieving the harbor of its heaviest burden by taking to sea a large part of the sewage which flows to the Lower East river and increasing the scope and magnitude of the work as necessity arises, appears to this Commission to be a necessary and sufficient solution of the problem. In no other way can the sewage be disposed of with so little chance of danger or offense. The project has the advantages that it will afford, at minimum expense, all the relief that is needed for the near future and is capable of expansion.

There are no shellfish industries in the vicinity of the proposed island and no currents which would carry any of the sewage to a bathing beach.* The sewage will not be exposed long enough to the air to cause annoying odors to be given off and there will be no opportunity for flies to breed.

The plan is in accordance with the best engineering precedent. There is no feature connected with it which is untried or experimental. It avoids offensive, complicated and uncertain processes of purification. It is based upon a careful consideration of the needs of the whole harbor. It leaves the waters of the inner harbor in a sufficiently improved condition for the assimilation of such sewage as cannot be kept out of the waters without wellnigh prohibitive expense.

Ultimate Digestion by the Sea Water. The project for carrying a part of the sewage to sea contemplates the treatment of the sewage at the island and the ultimate digestion of the liquid organic matter of the sewage by the sea water. Responsibility for the disposal of the sewage cannot cease until all the ingredients are rendered harmless and inert. It is important that the sewage shall not flow from the outlets as a coherent mass and that none of its elements shall be carried to the inner harbor or find their way, under the influence of wind or tide, to the shore. Accumulations of solid matter injurious to navigation must not be permitted to occur, nor must odors or flies or other objectionable features too commonly associated with sewage disposal works exist to mar the natural attractiveness and healthfulness of that part of the ocean where the outlet is located.

The liquid sewage matter will have a strong avidity for oxygen and will be rendered inert by the oxygen-saturated sea water with which it comes in contact. The great amount of water available at the point of outfall will have an abundant capacity to digest the liquid sewage.

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*For numerous long range float observations in the vicinity of the island, see Part IV, Chapter IV.

At first the form of treatment needed at the island will be settlement in tanks, perhaps aided, at times, by precipitants. In addition, it may be practicable to disinfect the sewage and produce a considerable amount of oxidation by the addition of bleach or electrolytically produced hypochlorite.

If at any time in the future it becomes desirable to completely purify the sewage, no such favorable location for the necessary works can be found in the metropolitan district than this artificial island. Owing to the shallowness of the water and the ease with which filling can be obtained, land can be made here for less money than an equal area can be bought on shore at any point not more distant from the New York City Hall. (See Figs. 31-35, Part IV, Chap. V, pages 600-602.)

In addition to the sewage from the Lower East river section, it will ultimately be feasible and desirable to send the sewage of the western Jamaica bay sub-division to the island for disposal. This would make it unnecessary to construct treatment works at Barren Island, as proposed in an earlier report of this Commission.*

Collecting the Sewage to the Outlet Island

Subdivision of the Territory. The territory included in the Lower Hudson, Lower East River and Bay Division has been separated by this Commission into 32 subdivisions for the purpose of laying out the works which will be necessary for the sanitary disposal of the sewage, and each subdivision has been given a number. The subdivisions numbered 1 to 12, inclusive, comprise that part of Manhattan which is naturally tributary to the Hudson river. Subdivisions from 13 to 26 are in Manhattan, Queens and Brooklyn, bordering upon the Lower East river. Subdivisions 27 to 31 are in Brooklyn and border on the Upper bay. Subdivision 32 borders on the Narrows and Gravesend bay.

The subdivisions vary in size and in the quantity of sewage which they produce. The boundaries which have been approximately established are intended to show the limits within which it will be feasible to collect the sewage to a central point on the water front in each subdivision. The central points are usually near existing large sewers and, as often as practicable, at places which are favorable for a prompt admixture of the sewage effluent with the harbor water.

As stated elsewhere in this report, the dry-weather flow of sewage, after collection to a central point in most of the subdivisions, should be passed through grit chambers and screens and so discharged into the water as to insure prompt diffusion.

The dry-weather flow of sewage produced in the following subdivisions bordering upon the Lower East river should be gathered to two central points, passed through grit chambers and fine screens, and discharged at the bottom of the deep channels: In Manhattan 13, 14 and 15, and in Brooklyn 22, 23, 24 and a part of 25.

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*See Chap. V, page 95.

The method of collection in those subdivisions from which the sewage is eventually to be carried to a distance may or may not be the same as in those subdivisions from which the sewage will be discharged into the neighboring waters as a permanent procedure. There are various ways in which the sewage can be collected. The Commission has spent a large amount of time in the study of this subject, and is of the opinion that the final choice should rest upon surveys and plans of a detailed character. One method may be described by way of illustration.*

The dry-weather flow and storm water equal to twice the dry-weather flow should be provided for. The excess should pass by storm overflows directly to the river.

The Necessary Interceptors. In designing the interceptors, it will be best to follow the European rather than the American practice. According to the American method, the interceptor is usually constructed entirely below the invert of the lateral sewer, with openings connecting the two, leaving the outer end of the lateral open for a storm overflow. The flow into the interceptor is controlled by a regulator, which is operated by a float. When the flow in the lateral reaches a certain amount, say twice the mean dry-weather flow, the regulator closes, cutting off the entrance to the interceptor and permitting the storm flow to discharge into the river by way of the original outlet.

According to European practice, the interceptor is built across the lateral sewer, its crown above the invert of the lateral. The interceptor therefore acts as a dam, preventing both the flow of sewage to the river, and the back flow of the tide from the river. All the sewage is diverted until the water surface in the lateral rises above and overflows the crown of the interceptor. The excess storm water then flows directly into the river. Where the crown of the interceptor is too high to permit such discharge, a special section may be adopted where it crosses the lateral.

The chief advantages of this arrangement are: The elimination of mechanical regulators, which are not always reliable; a raising of the hydraulic gradient in the interceptor and consequent reduction of lift at the pumping station; and less depth and consequently less excavation for the interceptors.

The interceptors should be large enough to accommodate twice the mean rate of flow during periods of dry weather. The maximum rate of dry-weather flow is assumed to be about one and one-half the average rate per 24 hours. This will permit the interceptor to carry off some of the first flush of storm water even if it reaches the plant during the hour of maximum sewage production.

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*See "Alternative Projects," page 130.

The intercepting sewers required to collect the sewage from the present sewers to the central points will lie as close to the surface of the ground as physical conditions permit. In making the plans and estimates, careful attention has been given to the information available concerning the geology of the territory passed through as determined by borings made by the Public Service Commission, Board of Water Supply and others.

The Manhattan Lower East Side Subdivisions. The total quantity of sewage to be taken from subdivisions 13, 14 and 15 is estimated at 99 million gallons per 24 hours in the year 1915. The estimated population for the same year is 680,500, and the area from which the dry-weather flow will be taken is 1,737 acres.

The south Manhattan interceptor will start near the foot of Broad Street with a size of 2 feet 6 inches, increasing to a diameter of 4 feet by the time it reaches Roosevelt Street. Here there will be a lift of about 5 feet by pumps and the interceptor will continue parallel to the water front with diameters enlarging from 5 feet 9 inches, to 8 feet 9 inches at East Street, Corlears Hook. The north interceptor will begin with a diameter of 12 inches at 26th Street and flow southerly, enlarging to 5 feet 6 inches at 14th Street where there will be a lift by pumps of about 6 feet. The interceptor will continue south with diameters increasing from 10 feet 6 inches to 10 feet 9 inches at East Street, Corlears Hook. At this point the sewage from both interceptors will pass through a grit chamber and fine screening plant and will then be pumped to temporary submerged outlets in the river.

The Inverted Siphon from Manhattan to Brooklyn. In the completed installation an inverted siphon will be required to carry the sewage from Manhattan to Brooklyn beneath the Lower East river. The point selected for the crossing is at a narrow part of the river where solid rock may be anticipated. The siphon which will be required to take the sewage produced in 1915 will have a diameter of 7 feet 8 inches. The depth will be 110 feet beneath the surface of mean low water. The siphon will be 2,400 feet long and extend from Corlears Hook to South 5th Street. The velocities in this siphon will range between 2 and 5 feet per second.

The Brooklyn Northwestern Subdivisions. That part of Brooklyn which is included in this project will be treated in a way similar to that described for collecting the sewage from the Lower East side of Manhattan. The quantity of sewage to be taken from this part of Brooklyn will be a little larger than the quantity from Manhattan or about 101 million gallons per 24 hours in 1915. The estimated tributary population in Brooklyn will be larger or 1,017,020 and the net area more than five times as large or 8,866 acres.

The South Brooklyn interceptor will commence at Classon Avenue with a diameter of 10 feet, taking the dry-weather sewage from the Classon Avenue sewer and increasing in diameter to 10 feet 8 inches at South 5th Street. The north interceptor will start at Huron Street with a diameter of 4 feet, increasing at Quay Street to 9 feet 10 inches, and reach South 5th Street with a diameter of 10 feet. At this point the combined flow will pass through a grit chamber and fine screens before discharge into the East river through submerged outlets. In both Manhattan and Brooklyn the interceptors have been designed of sufficient size to take the entire tributary flow up to the year 1960.

The foregoing represents the first stage of development recommended for the Lower East river section. In the completed installation the Manhattan sewage (99 mgd.) brought by a siphon from Corlears Hook will join the 101 mgd. collected from the Brooklyn side at South 5th Street, Brooklyn, where it will be pumped through three 6-foot steel force mains to the main sewer at Wallabout Street.

From this point it will be carried by a tunnel 12 feet 8 inches in diameter under Brooklyn and New York Lower Bay to the proposed outlet island about three miles off the Coney Island shore.

Profiles of the Manhattan and Brooklyn interceptors and of the main outfall tunnel are shown by Plates VI, VII and VIII, following page 124.

The General Pumping Station. The sewage collected at the general pumping station, amounting to about 200,000,000 gallons a day, will have been passed through grit chambers and screens and will be in reasonably fresh condition. The pumps will be required to raise the sewage at times of mean flow from an elevation of about 5 feet below mean tide and pump it under a head of about 29 feet to the artificial island at sea. The distance to be pumped will be about 12.9 miles and the head to be overcome will be that which is necessary in order to raise the sewage from the level at which it is delivered to the pumps to the level of the tanks where it is to be treated on the island, plus the head required to overcome the frictional resistance offered to the passage of the sewage through the long main. The pumps can be operated by steam, oil or by purchased electric current. It would seem feasible and desirable to drive the pumps with electric power to be obtained from burning the solid refuse of the city in destructors, as is commonly done in England and in certain large cities of Europe.

The Sewage Main to Sea. The force main through which the sewage will be pumped to the island will be built, for the most part, in tunnel. There will be three shafts, so situated as to permit the work of construction being pushed with expedition and economy. The internal diameter of the completed main will be 12 feet 8 inches.

The estimates given below are based upon the work already outlined, but since the sewage main will pass comparatively near Jamaica bay, it may be desirable to modify the plan which this Commission proposed for the Jamaica Bay Division* to such an extent as to permit the main to take to the island the sewage which it has been proposed to collect from Brooklyn to Barren Island for treatment and disposal. The advantages to be gained by this change are (a) reduction in cost over the Barren Island project and (b) avoidance of the necessity of constructing a sewage disposal plant at the entrance of Jamaica bay. By adding the sewage of the western Jamaica bay subdivision to the sewage of Manhattan and Brooklyn which is pumped to the island, the disposal works will be centralized and questions of administration and maintenance will be simplified.

The Western Jamaica Bay Subdivision. If the sewage from the western part of the Jamaica Bay Division is taken to the proposed island for discharge at sea it will be collected at two central pumping stations, one at Hendrix Street and the other at Flatlands Avenue. From the eastern pumping station, an interceptor 9 feet to 9 feet 6 inches in diameter will extend for 2.6 miles to a second pumping station at Flatlands Avenue. From this point the interceptor, enlarged to 11 feet 4 inches in diameter, then 11 feet 8 inches and finally to 12 feet in diameter, will extend to Nostrand, where it will be joined by a small interceptor of 27 inches from the present sewage disposal works for Sheepshead bay, which will be converted into a pumping station. The interceptor enlarged to 12 feet 4 inches will end at a pumping station to be located at Ocean Parkway and Avenue W. This last pumping station will discharge the sewage into the main which runs to the island.

A pumping station to be located at 86th Street and Avenue V in Bensonhurst will discharge through a 4-foot interceptor to the pumping station which will serve the western part of the Jamaica Bay Division. The sewage of Coney Island will be pumped from the present plant known as Caisson No. 3 directly to the main sewer.

The quantity of sewage from the western part of Jamaica bay will be about 47,000,000 gallons per day in 1915. The population will be about 343,000 and the area served 19,000 acres.

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*See Chap. V, page 97, also Plate V, following page 98.

The Artificial Island. The tunnel to the island, if sewage from the Western Jamaica Bay Division is admitted, will be 14 feet in diameter and constructed at a depth of about 60 feet, the material to be penetrated being sand. It will be possible to construct the tunnel with two headings, one from the shore and one from the island, the two meeting and being properly joined.

The point selected for the island has been carefully chosen with reference to economy of construction, resistance to the destructive influences of tidal currents and storms, freedom of obstruction to the free flow of tidal water in and out of the harbor and absence of sanitary objections.

The location lies to the north of Sandy Hook and to the south of Coney Island. Its position is latitude 40 degrees 31½ minutes and longitude 73 degrees 58½ minutes. The water within a mile from the island in all directions varies between 7 and 40 feet in depth, the average being about 20 feet at mean low tide.

The plan of the island is approximately rectangular, the seaward side being rounded. The area at the start will be about 20 acres. This can be extended as required. The general plan of the island is shown on Fig. 2, page 122.

The outer face of the island will be a wall of riprap composed of large pieces of broken stone carried to the site on boats and laid upon the hard sandy bottom (see Figs. 2 and 3). It is expected that some settlement will occur, due to the water cutting sand away from under the stone. When sufficient riprap has been bedded to stop this action of the water, no more settlement is to be expected. The main bulk of the island will be composed of sand supplied from a suction dredge, which will take its supply from the bottom of the sea in the vicinity.

The height of the island above mean low water will be about 18 feet. The length will be 1,300 feet and the width 1,000 feet. The side of the riprap wall which is exposed to the sea will have a slope of 1 vertical upon 3 horizontal below mean high water, and 1 upon 2 above, while the other sides will have a slope of about 1 on 2. The cost of constructing the island has been estimated at about $615,000.

The landward side of the island will be provided with a quay wall for the accommodation of vessels engaged in taking supplies and other materials to and from the island. Shelter from the sea will be provided by a breakwater, which will enclose a small harbor.

The island will contain a plant of settling tanks in which the sewage will have an opportunity to deposit its solid matters during a period of about two hours. These tanks will be of modified Dortmund tank construction, similar to those recently constructed at Toronto, Canada. Provision will be made for treating the sewage if necessary with a coagulant before passing it into the tanks.

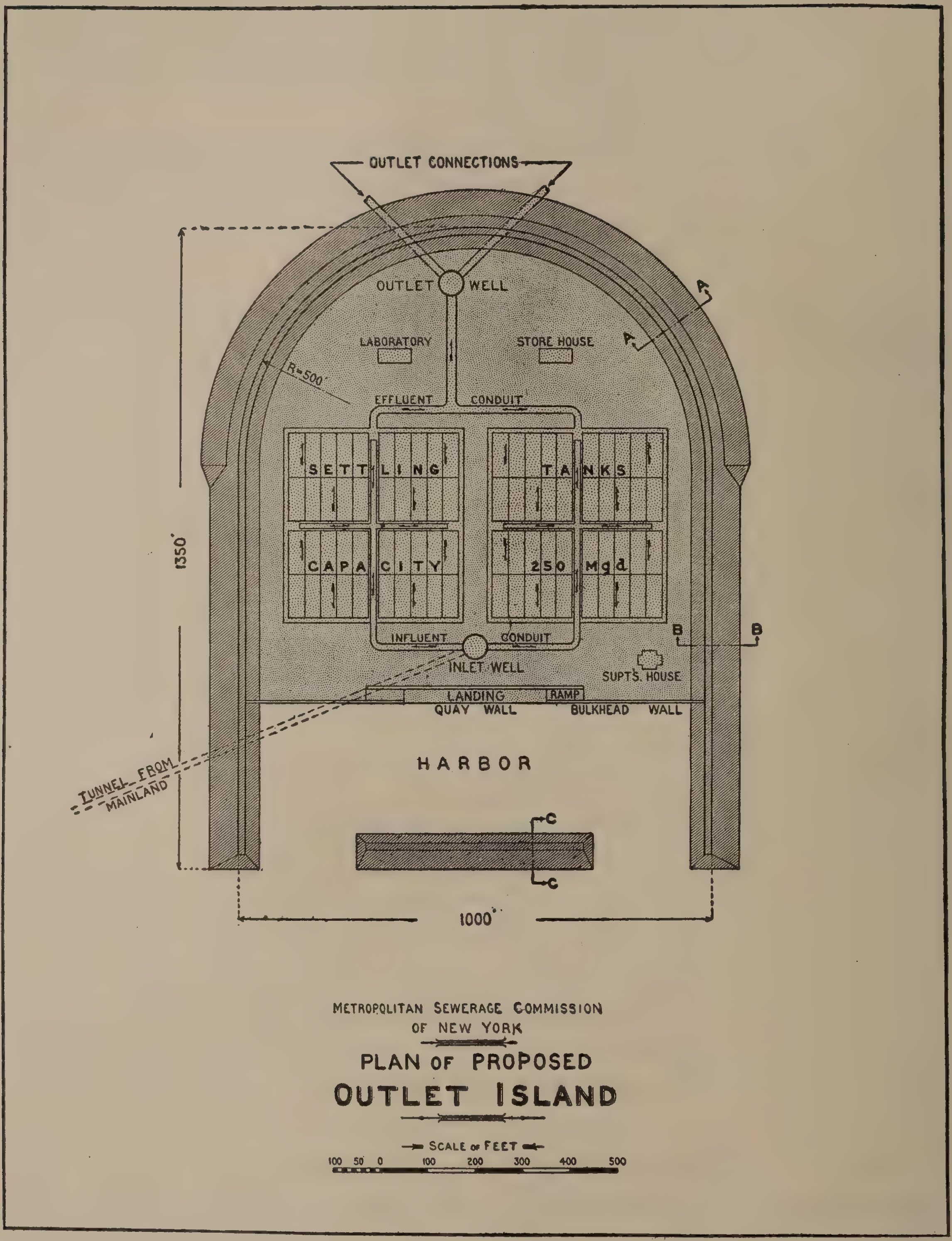
OUTLET CONNECTIONS
OUTLET WELL
LABORATORY
STORE HOUSE
A
A
R=500'
EFFLUENT CONDUIT
SETTLING TANKS
CAPACITY 250 Mgd
INFLUENT CONDUIT
INLET WELL
B
B
SUPT'S. HOUSE
LANDING
RAMP
QUAY WALL
BULKHEAD WALL
1350'
HARBOR
TUNNEL FROM MAINLAND
C
C
1000'
METROPOLITAN SEWERAGE COMMISSION
OF NEW YORK
PLAN OF PROPOSED
OUTLET ISLAND
SCALE OF FEET
100 50 0 100 200 300 400 500

FIG. 2

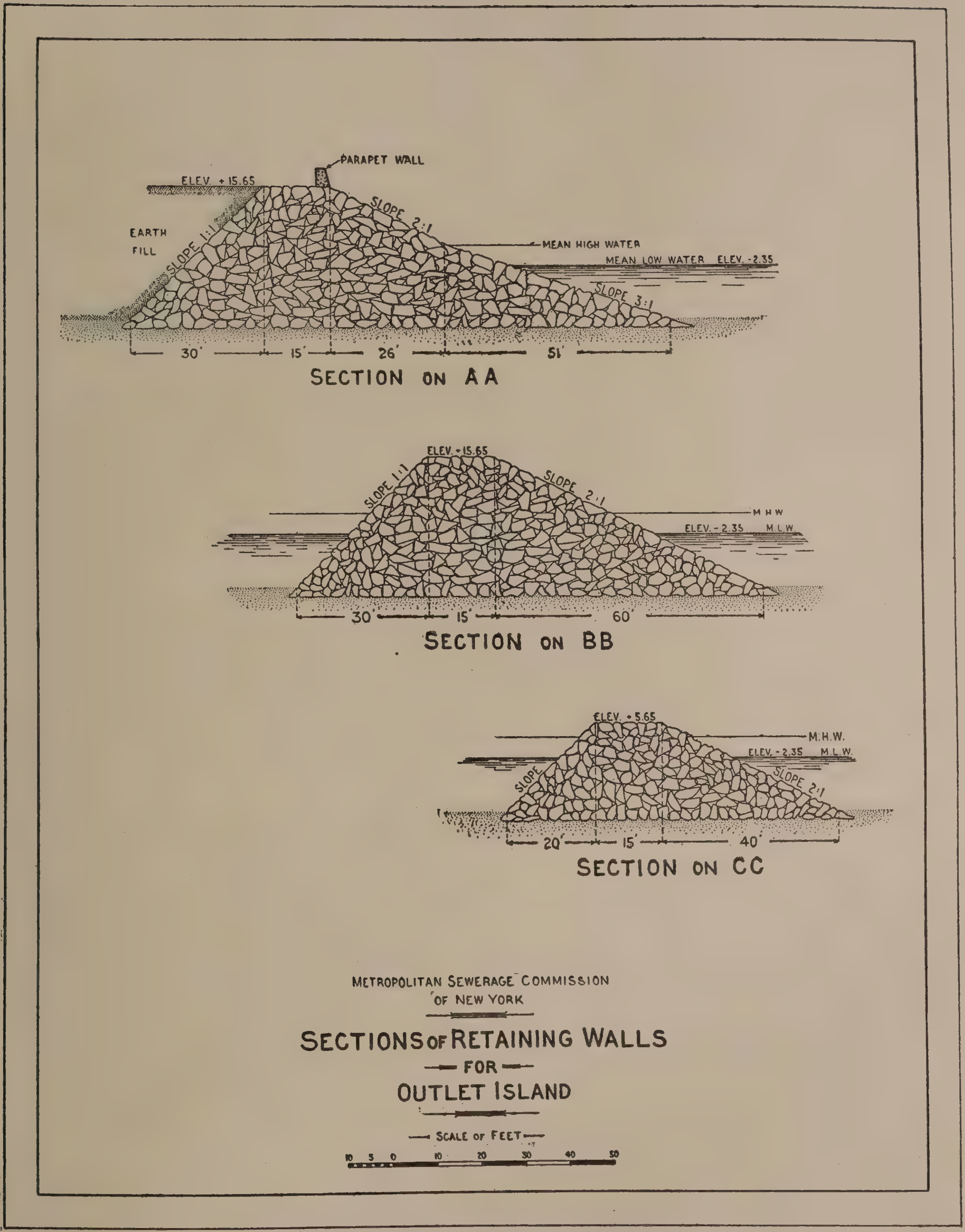
PARAPET WALL
ELEV. +15.65
SLOPE 2:1
EARTH FILL
SLOPE 1:1
MEAN HIGH WATER
MEAN LOW WATER ELEV. -2.35
SLOPE 3:1
30'
15'
26'
51'
SECTION ON AA
ELEV. +15.65
SLOPE 1:1
SLOPE 2:1
M H W
ELEV. -2.35 M.L.W.
30'
15'
60'
SECTION ON BB
ELEV. +5.65
M.H.W.
ELEV. -2.35 M.L.W.
SLOPE
SLOPE 2:1
20'
15'
40'
SECTION ON CC
METROPOLITAN SEWERAGE COMMISSION
OF NEW YORK
SECTIONS OF RETAINING WALLS
FOR
OUTLET ISLAND
SCALE OF FEET
10 5 0 10 20 30 40 50

FIG. 3

After treatment, the sewage will be discharged through a number of outlets arranged radially on the seaward side of the island. If desirable, it will be feasible to pump sea water into the sewage and provide for the mixture of the two before the discharge takes place. Such admixture would facilitate the immediate diffusion of the sewage in the sea water, but the active agitation and free movement of the great volume of water in the vicinity of the island will probably make the preliminary admixture of sea water and sewage by pumping unnecessary.

The material which settles out in the tanks will be carried to sea in boats and dumped.

Cost. This project will require the construction of about 6.6 miles of intercepting sewers in Manhattan and Brooklyn. The siphon from Manhattan to Brooklyn will be a little less than a half mile long. The main from the pumping station to the island will be about 13 miles long. If the Jamaica bay sewage is brought to the island, about 2 miles of collectors and 7 miles of interceptors will be required in addition.

For the first installation of this project, the estimated cost of construction is $4,095,000, and the total maintenance and fixed charges will amount to about $361,000 per year.

For the entire installation, including the main pumping station, outfall tunnel, island and treatment works, the total cost of construction would be about $17,394,000, and $4,072,000 additional for the Jamaica Bay Division if included. The total maintenance and fixed charges would amount to about $1,311,500, with $286,000 additional chargeable to the Jamaica Bay Division.

RECOMMENDATION OF THE COMMISSION AS TO THE FIRST INSTALLATION

In the opinion of the Commission, it would be desirable but not necessary to carry out the island project as a first installation. The fine screening proposed, although the most thorough treatment practicable in this section, would afford relief to the Lower East river only for a time. The improvement effected by discharging through submerged outfalls instead of at the pierhead line would alleviate conditions in the slips and along the shore, but would not make the water permanently satisfactory nor alter the dilution ratios of sewage to water in the river as a whole. Any benefit accruing from this procedure would be neutralized later by the increase in the volume of sewage to be disposed of.

In comparing the projects for local sedimentation treatment as considered at one time by the Commission, with that in which the entire 200 mgd.* is taken to the ocean,

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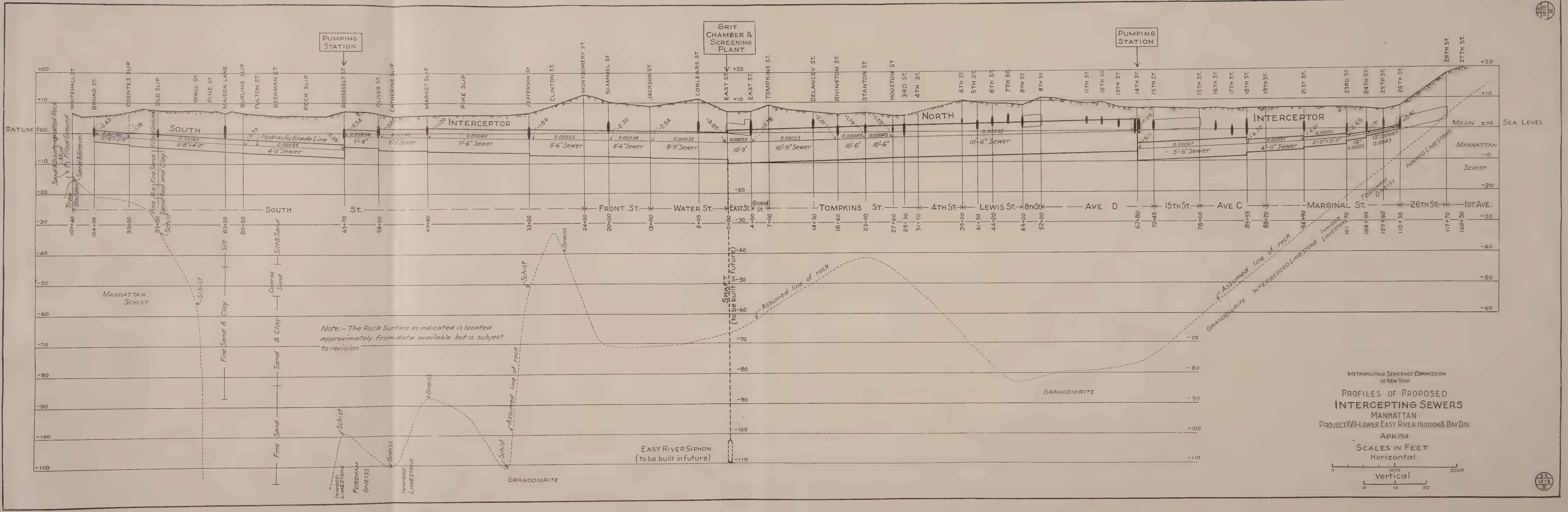
*Million gallons per day.

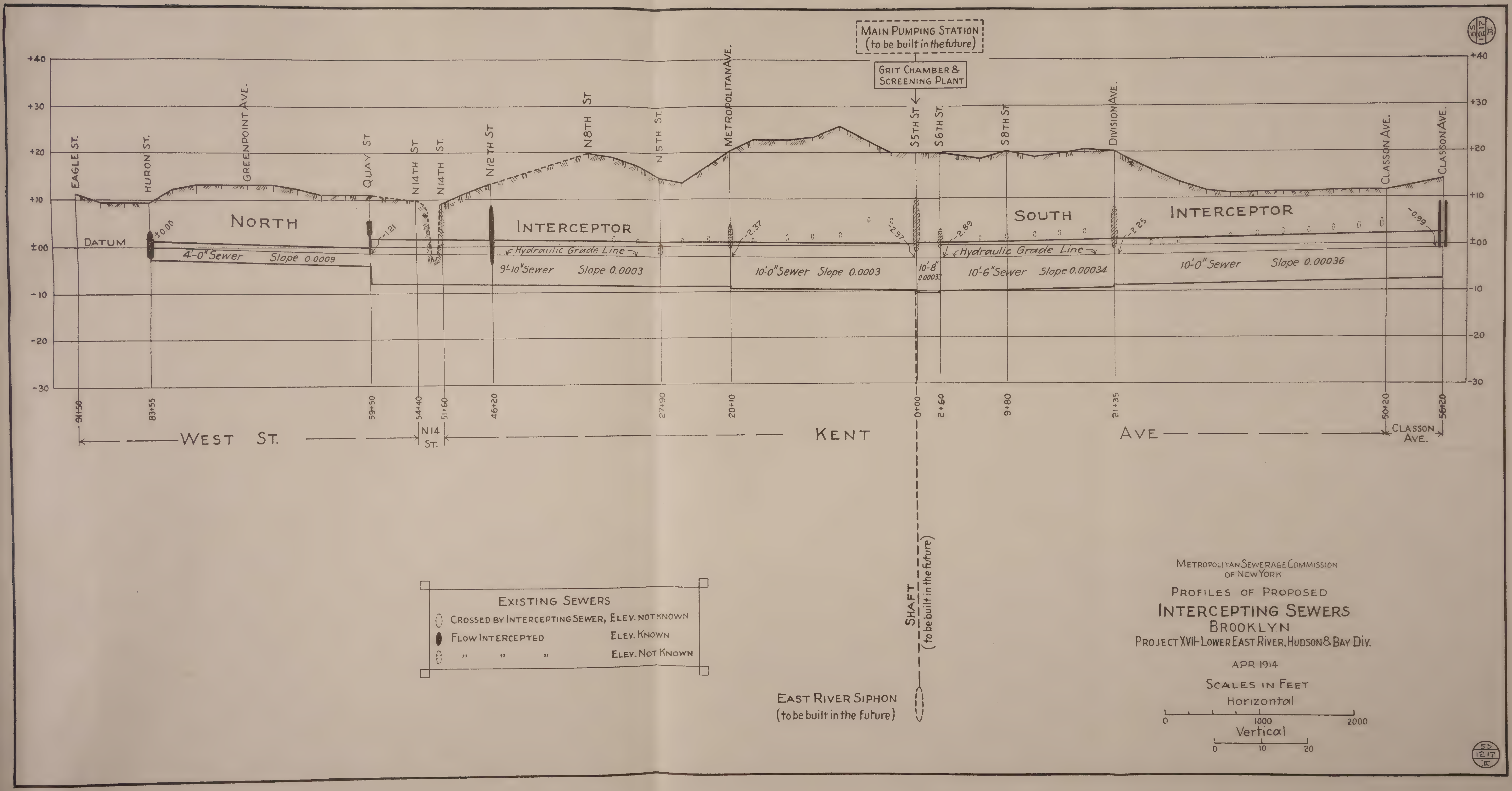


Note:- The Rock Surface as indicated is located approximately from data available but is subject to revision

METROPOLITAN SEWERAGE COMMISSION
OF NEW YORK

PROFILES OF PROPOSED
INTERCEPTING SEWERS
MANHATTAN
PROJECT XVII-LOWER EAST RIVER HUDSON & BAY DIV.
APR. 1914

SCALES IN FEET
Horizontal
0 1000 2000
Vertical
0 10 20



EXISTING SEWERS

⬭ CROSSED BY INTERCEPTING SEWER, ELEV. NOT KNOWN
● FLOW INTERCEPTED ELEV. KNOWN
▨ " " " ELEV. NOT KNOWN

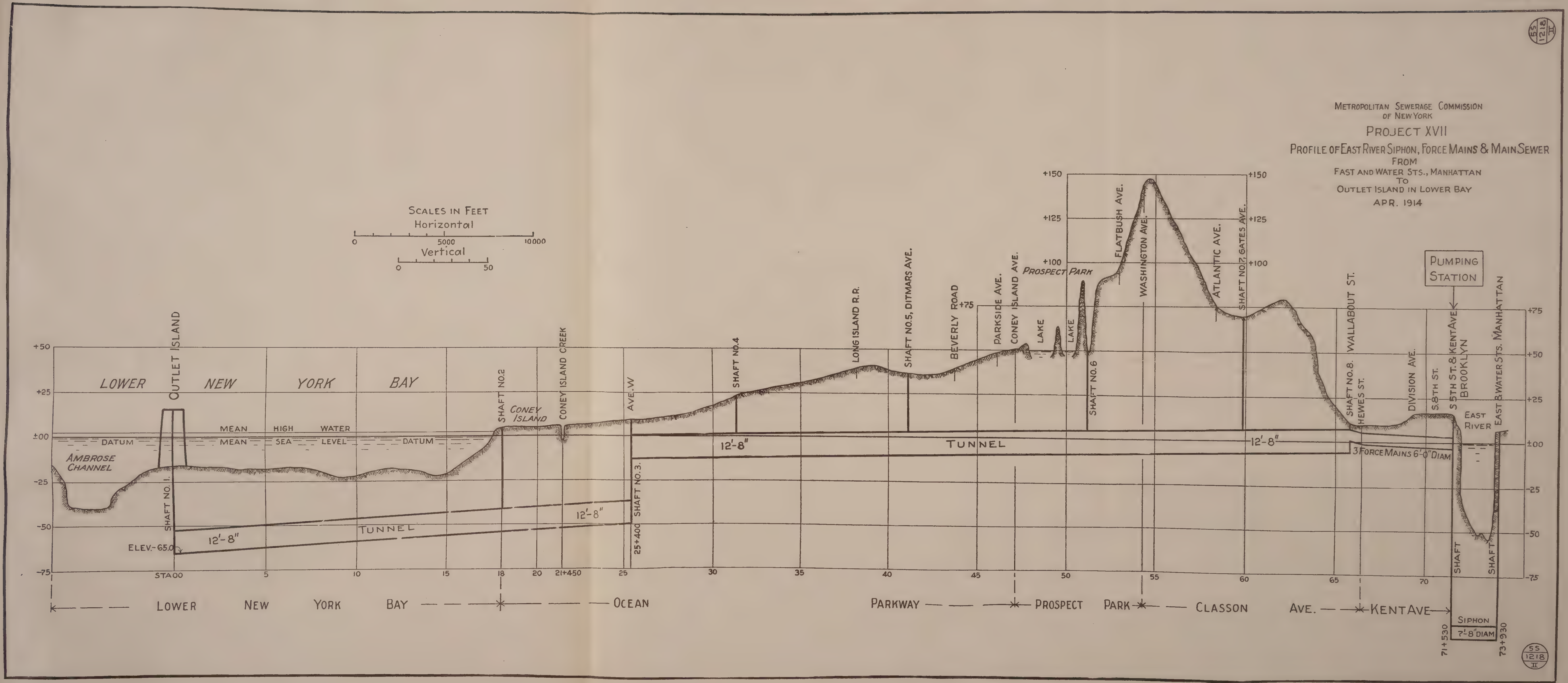
METROPOLITAN SEWERAGE COMMISSION
OF NEW YORK

PROFILES OF PROPOSED
INTERCEPTING SEWERS
BROOKLYN
PROJECT XVII - LOWER EAST RIVER, HUDSON & BAY DIV.

APR 1914

SCALES IN FEET
Horizontal

Vertical



METROPOLITAN SEWERAGE COMMISSION
OF NEW YORK

PROJECT XVII

PROFILE OF EAST RIVER SIPHON, FORCE MAINS & MAIN SEWER
FROM
FAST AND WATER STS., MANHATTAN
TO
OUTLET ISLAND IN LOWER BAY

APR. 1914

it must be remembered that by the former project the tank effluent would carry to the East river 70 per cent. of the organic matter contained in the sewage. Now, if it is assumed, as seems fair, that but 25 per cent. of the total organic matter capable of reducing the dissolved oxygen of the harbor is removed by this process, it follows that, to produce an improvement of the water equivalent to the removal of 200 mgd. of sewage to the ocean, it would be necessary to treat 800 mgd. by screening. This is more sewage than will be produced in the whole city in 1915.

In other words, if all the sewage of Greater New York were treated by fine screening, it would not improve the general condition of waters of the harbor as much as the entire removal of the 200 mgd.

Opinion of U. S. Engineers on the Proposed Island

Recognizing that responsibility for the maintenance of a proper depth of water for navigation in the harbor rested with the U. S. War Department and that the island proposed by the Commission for the disposal of the sewage of the Lower East river could be constructed only with the permission of that Department, application was made to the Secretary of War requesting the views of the War Department with respect to this subject. The Commission's application was referred by the Secretary of War to the Chief of Engineers, U. S. Army, and by him to the New York Harbor Line Board for report.

The New York Harbor Line Board consisted of Colonels W. T. Rossell, W. M. Black and S. W. Roessler of the Corps of Engineers, U. S. Army. The island would be in that part of the harbor which is under the special jurisdiction of Col. Roessler, who has had much experience with breakwaters and other structures intended to resist the destructive action of the sea. The Harbor Line Board gave a hearing on the Commission's project on March 7, 1913. On that occasion the subject was thoroughly discussed, plans, charts and profiles of the proposed structures being produced.

The opinion of the Harbor Line Board was transmitted to the Commission by the War Department on March 22, 1913. It was to the effect that an island in either of the two locations suggested by the Commission, one of which is shown on Plate I, following page 48 of Preliminary Report VI of the Metropolitan Sewerage Commission, would not interfere unduly with navigation nor have an unfavorable effect upon the harbor. In this opinion the Chief of Engineers concurred.

The correspondence in full follows:

February 18, 1913.

Hon. Henry L. Stimson,
Secretary of War,
Washington, D. C.

Sir: In making plans for a sanitary disposal of the sewage of New York City, it has become desirable to consider the practicability of constructing an island near the entrance of New York harbor. The island would be located on one of the shallow, sandy bars which are divided by the Fourteen Foot Channel to the north of Ambrose Channel.

The island would be constructed with an enclosing wall of riprap and a filling of sand or other solid material, the total area occupied being less than 30 acres. Upon the island would be tanks and other structures in which much of the solid matters of the sewage would be removed to be carried to sea in boats or disposed of in some other acceptable manner, while the clarified effluent would be discharged into the surrounding water through outlets so arranged as to insure its prompt dispersion and disappearance. The sewage, amounting to about 200,000,000 gallons per twenty-four hours, would be brought to the island through a tunnel.

Recognizing the authority which is exercised by the general government over the navigable waters, this Commission desires to place its project in sufficient detail before you, to the end that an early determination may be reached as to the permissibility of constructing and using this island in the manner, and for the purpose, stated.

Members of this Commission will be pleased to call upon you with reference to the subject in case you visit New York, or they will go to Washington to see you, if preferable. The technical details of this plan can be laid before such army engineer, officer or officers of the New York Harbor Line Board as you may designate.

Your early attention to this subject is requested in order that the result of your consideration may be known in time to be used in a report soon to be issued by this Commission.

Respectfully,
George A. Soper,
James H. Fuertes,
H. deB. Parsons,
Charles Sooysmith,
Linsly R. Williams,
Commissioners.

March 3, 1913.

Mr. George A. Soper, President,
Metropolitan Sewerage Commission,
17 Battery Place, New York City.

Dear Sir: 1. The Harbor Line Board has before it your application of Feb. 18 to the Secretary of War concerning the construction of an artificial island near the entrance to New York harbor, and also a letter of Feb. 19th from Mr. H. deB. Parsons, Consulting Engineer, requesting that this matter be laid before this Board. In order that the Board may be able to come to a definite conclusion in the case, it is requested that you submit more detailed plans and make a definite application for such construction.

2. The Board desires to take this matter up at 10 A. M. on March 7th and it is requested that these plans be submitted before this time and that if possible you or your representatives be present to confer with the Board in the matter on that date.

Very respectfully,
WILLIAM T. ROSSELL,
Colonel, Corps of Engineers,
Senior Member of Board.

MARCH 6, 1913.

COLONEL WILLIAM T. ROSSELL,
Corps of Engineers, New York Harbor Line Board,
Army Building, New York City.

DEAR SIR: Your letter of March 3, relating to the proposal of this Commission to construct an island near the mouth of New York harbor, has been received.

Application is hereby made for permission to construct and maintain an island for the treatment and disposal of sewage in accordance with the following plan:

The object of constructing the island is to afford opportunity for the treatment and final disposition of a quantity of sewage from the inner harbor sufficient to relieve and protect the inner harbor from its excessive burden of pollution.

The location proposed for the island is in shoal water, preferably in latitude 40° 32′ 02″ N, longitude 73° 59′ 46″ W, or in latitude 40° 31′ 26″ N, longitude 73° 58′ 21″ W.

In plan, the island would be approximately rectangular except that the seaward side would be rounded. The area at the start would be about 20 acres of filled land and about 10 acres of harbor for the protection of vessels engaged in transporting supplies to the island and taking sludge and other materials away.

The outer face of the island will be a wall of riprap composed of large pieces of broken stone carried to the site on boats and laid upon the hard sandy bottom. It is expected that some settlement will at first occur, due to the water cutting sand away from under the stone. The main bulk of the island will be composed of sand supplied from a suction dredge which will take its supply from the bottom of the sea, or earth, ashes and other suitable material.

The height of the island above mean low water will be about 18 feet. The length of the island, when first constructed will be about 1,300 feet and the width 1,000 feet. The side of the riprap wall which is exposed to the sea will have a slope of 1 vertical upon 3 horizontal and the two adjoining sides will have an outer slope of about 1 on 2. The riprap will be 15 feet across the top and will be surmounted by a concrete parapet wall 4 feet in height. The riprap will be from 75 to 122 feet wide on the bottom, according to the location with respect to the sea.

The island will contain a plant of settling tanks in which the sewage will have an opportunity to settle and deposit its solid matters during a period of about two hours. These tanks will be of modified Dortmund tank construction, similar to those recently constructed at Toronto, Canada. Provision can be made for treating the sewage, if necessary, with a coagulant before passing it into the tanks.

After treatment, the sewage will be discharged through a number of outlets arranged radially from the island in such position as to bring about the most immediate and perfect dispersion of the sewage practicable. If desirable, it will be feasible to pump sea water and mix it with the sewage before the discharge takes place. Such admixture would facilitate the immediate diffusion of the sewage in the sea water; but the active agitation and free movement of the great volume of water in the vicinity of the island will, it is expected, make a preliminary mixture of sea water and sewage by pumping unnecessary.

The material which will settle out of the sewage in the tanks will be carried to sea in vessels and dumped sufficiently far from the land to insure that no trace will reach bathing beaches, inhabited shores or oyster grounds.

Provision will be made for a laboratory and dwelling house for those who will be needed to operate the tanks and other devices for the treatment and discharge of the sewage. It will be feasible to maintain a light on the island for the benefit of navigation, in case this is desirable.

In course of time, it will be necessary to increase the size of the island and it is proposed that this will be done by extending its length so that the total area covered will be about three times that of the original island, or, approximately, 70 acres.

The quantity of sewage which will be brought to the island at the beginning is estimated at about 203,000,000 gallons per 24 hours during dry weather. During storms, this volume will increase about 100 per cent. This sewage will be collected from those parts of Manhattan and Brooklyn whose drainage is naturally tributary to the Lower East river between the Battery and 28th street, Manhattan. It is proposed to collect the sewage by building intercepting sewers close to the water front to receive the sewage from the existing combined sewers and gather it to a central pumping station to be located near the Brooklyn Navy Yard. A siphon built beneath the East river will carry the sewage of Manhattan to the Brooklyn side. At the central pumping station the sewage will be pumped through a force main built as a tunnel to the island. The tunnel will be over 20 feet beneath the bottom of the Lower bay and so be free from injury to anchors even in the deepest parts of the channel between the island and the mainland where vessels rarely anchor. The sewage will consist of the ordinary dry-weather flow except at periods of rainfall when the storm water from the streets will also be received to the extent of about once the volume of the average hourly production of house sewage.

All the sewage which is sent to the island will have been passed through grit chambers and screens with openings not larger than one-half inch. The sewage from Manhattan will be screened before passing to the Brooklyn side. Since it will be relatively fresh, it is estimated that no less than 15 per cent. of the suspended matter will be extracted. Grit chambers will be located near the screens and their efficient operation will be insured by the necessity which will exist for removing the readily settleable material from the sewage in order to prevent obstructions in the siphon and interference with the pumps. The Brooklyn sewage will be passed through screens and grit chambers no less effective than those of Manhattan before the sewage is pumped through the force main. It is estimated that the settling basins on the island will remove at least 60 per cent. of the suspended matter from the sewage. It is expected that the total effect of the treatment by grit chambers, screens and settling basins will be to remove considerably more than 75 per cent. of the suspended matter originally present.

It is believed by this Commission that either of the two locations here proposed for the island will be favorable for the sanitary disposal of the sewage and will be free from objection from the standpoint of navigation. Both sites are upon sand reefs where no vessels except fishing craft of lightest draft are likely to pass. The area of the island, even when extended to the dimensions which may ultimately be necessary, will be so small, as compared with the total area of the Lower bay, as not seriously to interfere either with the tidal prism or with the force or direction of the tidal currents flowing in and out of the harbor. The amount of solid matter contained in the sewage when discharged will be slight as compared with the volumes of water in the vicinity of the island and the action of the waves and currents in this part of the harbor are so active that it seems improbable to this Commission that deposits of any serious extent would be formed, even if the sewage was to be discharged in crude condition.

Apart from permission to build the island, which this Commission would interpret as expressing a belief that no interference would be caused by the island to navigation, this Commission would value the opinion of the Harbor Line Board as to the probable capacity of the island to resist the destructive action of the sea. It is recognized that the Army Engineers possess the qualifications of experts on this subject. If material criticism can be brought against the proposal of this Commission for the construction of the island on the score of structural defect, suggestions looking to a more durable form of construction would be regarded in the light of a public service.

Accompanying this letter is a chart of Lower New York bay, showing the two alternative locations for the proposed island, a profile giving the line of the tunnel through which the sewage would be pumped to the island, a plan of the island and three cross sections of the retaining walls.

Respectfully,
George A. Soper,
President.

Separate Screening Plants

It will be impracticable to remove from the inner harbor all the sewage from the Lower East river, Hudson and Bay Division. That which is not included in the recommended project for the Lower East river will be treated by locally placed grit chambers and fine screens and discharged locally through submerged outlets. Marginal sewers will be necessary to concentrate the sewage at the proposed plants, whose locations are shown approximately upon the frontispiece to this report.

Following is an estimate of cost of a few typical plants:

Riverside Park at West 96th Street, Manhattan

A fine screening plant and grit chamber would be located in Riverside Park at West 96th Street, with submerged outlets extending to 300 feet off the West 96th Street pier. The capacity would be three times the dry-weather flow of 30 million gallons per day. The storm outlets carried to the end of West 97th Street pier would have a capacity of 270 million gallons per day.

Estimate of Cost

Treatment Plant		
Excavation	$ 9,000	
Sub-structure	13,500	
Superstructure	25,500	
Machinery	29,000	
Contingencies—15%	12,000	$ 89,000
Outlets for Dry-Weather Flow		
Treatment plant to existing sewer	$ 1,200	
Present outlet to 300′ off pierhead	23,000	24,200
Outlets for Storm Overflow		
Treatment plant to bulkhead line	$16,250	
Bulkhead line to pierhead	20,750	37,000
Total cost of plant and outlets		$150,200

Orchard Street, Astoria

A fine screening plant and grit chamber, with pumps for low level sewage only, would be located at the foot of Orchard Street, Astoria. The capacity would be 87 million gallons per 24 hours or three times the dry-weather flow.

Estimate of Cost

Excavation	$ 4,662
Substructure	10,250
Superstructure	20,000
Machinery	36,100
Contingencies—15%	10,688
Total Cost	$81,700

64th Street, Brooklyn

A fine screening plant and grit chamber would be located at the foot of 64th Street, Brooklyn. The capacity would be 150 million gallons per 24 hours or three times the dry-weather flow.

Estimate of Cost

Excavation	$ 6,900
Substructure	17,500
Superstructure	65,400
Machinery	35,000
Connection with sewer	2,200
Contingencies—15%	20,000
Total Cost	$147,000

ALTERNATIVE PROJECTS FOR DISPOSING OF THE SEWAGE OF THE LOWER EAST RIVER, HUDSON AND BAY DIVISION

Possible Directions in Which to Take the Sewage

There are not many directions in which the sewage from the Lower East River Section can be taken. It would be impracticable to carry it north into Westchester County, for the land there lies at too great an elevation. It would be impossible to carry it west because the people of New Jersey would object to receiving it. The idea of discharging it into the Hudson river cannot be entertained, for if this were done that stream would become too heavily polluted. Sentimental considerations require that the Hudson shall not be made a receptacle for the sewage from other parts of the harbor.

It would not be feasible to carry the sewage to Long Island sound; the distance would be too great, the volume of water there available would be insufficient, the danger of polluting extensive shellfish beds would be large, and the risk of contaminating the shores in the vicinity of villages, towns and country estates too imminent.

The sewage could not be taken east on Long Island, except to a distance of 30 or 40 miles, for its disposal would be certain to produce nuisance and, consequently, serious injury to property already occupied for residence purposes or likely soon to become valuable for this purpose. Furthermore, opportunities for the disposal of the effluent of treatment works are lacking on Long Island, the north shore of which is deeply indented with bays and, for the most part, high and rocky, and the south shore bordered with broad, shallow bays and marshy islands, where the flow of tidal water is relatively slight.

Staten Island Not Suitable for Very Large Sewage Works

To the southwest of this division lies the Borough of Richmond, or Staten Island, and much sewage could be brought there for treatment as far as engineering considerations are concerned. There are several thousand acres of marshy land on the west side of this island bordering the Arthur Kill which might be employed for sewage disposal, provided no nuisance were produced.

The sewage could be taken to the disposal works by a tunnel which could be driven beneath the waters of Upper New York bay to the north shore of Staten Island, and thence through the high land to the low-lying area near the Arthur Kill. The Arthur Kill has been dredged for the convenience of ships and could receive a well purified effluent, although owing to its small volume of flow and the oscillating effect of the tide, the capacity of the Arthur Kill for unpurified sewage is comparatively small. If the sewage could not be purified sufficiently to discharge the effluent into the Arthur Kill, it would have to be carried by tunnel eastward from the treatment works to the waters of Lower New York bay.

It is probable that treatment works capable of purifying the sewage to such an extent as would permit the effluent to be discharged into the Arthur Kill would be impracticable on Staten Island. Apparently some oxidizing process, either sprinkling filters or possibly contact beds, would have to be employed. It is probable that if either of these processes were used to treat the quantity of sewage which would have to be dealt with, not less than 200,000,000 gallons per 24 hours, with a certainty of more later on, objectionable sanitary conditions would be produced. The sewage would be septic and, consequently, likely to produce odor when brought into contact with the air either in the fine spray necessary in sprinkling filters or in the large areas of surface exposed by the broken stone of contact beds. The likelihood of trouble from flies, a frequent and annoying feature in sewage works, should also be considered. The peculiar mist which sometimes hovers in calm weather over extensive areas of sprinkling filters would prove a source of grave concern to property holders, even at a considerable distance from the works. Before the authorities of the Borough of Richmond would give their consent to receiving the sewage of this division in that borough for disposal, it is probable that they would insist upon more assurance of immunity from nuisance than safely could be given.

Added to the sanitary difficulties which would attach to the disposal of the sewage by works upon Staten Island is the consideration of cost. It would be expensive to carry the sewage of this division to Staten Island and there dispose of it. The tunnels would be long and, in places, very deep. The foundations for the works on the lowlands in the western part of Staten Island might prove difficult of construction. The outlet tunnel for the effluent would be long and costly.

Possibility of Treatment on an Artificial Island in the Inner Harbor

The Commission has made an investigation of alternative projects for carrying the sewage of the Lower East river section to an artificial island nearer than the proposed sea island.

The first alternative contemplated an island of about 20 acres just south of, or built as an extension to, Blackwells Island in the East river. The treatment proposed was chemical precipitation, the sludge to be carried by steamers to sea and dumped there. After treatment, the sewage would be discharged into the East river through three submerged outfalls. The sewage would be collected from the Manhattan and Brooklyn shores by interceptors built above tidal influence, the district lying between the interceptor and the shore to be resewered so as to drain into the interceptor. The collectors were designed to carry twice the the mdwf.* expected by 1960.

Pumping stations would be located at Corlears Hook, Manhattan, Wallabout Street, Brooklyn, and on the proposed island. The sewage would pass through screens and grit chambers before reaching the pumps.

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*Mean dry-weather flow.

The cost would be $20,694,000, and the annual charges $2,117,700. These amounts are larger than the estimates for the ocean island project, and the project would not afford as much relief to the Lower East river.

The second alternative involved the construction of an island in the Upper bay, off Red Hook, just south of Governors Island. The method of collection was to be similar to that proposed in the Blackwells Island scheme. The screens and grit chambers would be located at Corlears Hook, Manhattan, Borden Avenue, Queens, and Wallabout Street, Brooklyn. The single pumping station would be located at the island. The estimated cost was $23,933,000 and the annual charges $2,309,400.

The point of discharge would be almost in the path of vessels in the main channel. The sewage would be carried to the Lower East river by the flood currents, thus defeating the purpose for which it was taken to the island. The proposed Passaic Valley Sewer outlet would be about 2½ miles distant, and it is probable that the combined volume of sewage from these two outlets, even after partial purification, would overburden this part of the Upper Bay.

Objections to Collection at Barren Island

Two other possible means of disposing of the sewage of this division remain to be considered. First, collection to the vicinity of Barren Island, near the mouth of Jamaica bay, and treatment there, with a discharge of the effluent at sea. Sanitary considerations, such as have been mentioned in connection with the possibility of carrying the sewage to Staten Island, would weigh heavily against purifying the sewage any more completely than is absolutely necessary at this point. The outlet would therefore have to be long enough to carry the sewage far from shore.

Unless the sewage were purified in bacteria beds, it would be necessary to extend the outlet some miles out to sea beyond Rockaway Point in order to make sure that the sewage would not be carried back to the land by the wind and tide, and there are practical difficulties in the way of doing this. The necessary tunnel for this purpose would be very difficult to construct. It would have to be at least 75 feet below the surface of the water, in order to cross well beneath the deep, swiftly-flowing channels of Rockaway inlet. The water at this point is between 40 and 50 feet deep at low tide. Proceeding seaward it would not be found desirable to approach much nearer the surface with it. The point of outfall should probably be located about two miles from shore. This would be an unfavorable location for an outlet crib or other permanent structure, for it would be exposed to the full force of the Atlantic ocean and the shifting sands. This project thus has weighty arguments against it.

Estimate of Cost of Disposing of 250 Million Gallons of Sewage Per Day from a Crib Outlet in Lower New York Bay

As far as the Lower East river, Hudson and Bay Division is concerned, the scheme is practically identical with that outlined, but in this plan the sewage from that part of the Jamaica Bay Division located in Brooklyn would be added to the sewage from the Lower East river, Hudson and Bay Division at the Coney Island pumping station after passing grit chambers and screens. The part relating to the Jamaica Bay Division may be considered a revision of the recommended project, but with the Coney Island pumping station near caisson No. 3, instead of Barren Island, the objective point of concentration.

The estimates are based on the 1915 flow from:

Manhattan—Lower East river, Hudson and Bay Division	99 mgd.
Brooklyn — " “ “ “ “ “ “	104 “
Brooklyn —Jamaica Bay Division	47 “
Total	250 mgd.

The sizes of interceptors are based upon the anticipated sewage flow of 1960 except in crossing the East river and Coney Island ship canal and running northerly from the Wallabout pumping station in Brooklyn. These, with the outfall tunnel between the Wallabout pumping station and the outlet, would require duplicating in order to accommodate the flow expected in 1960.

The Jamaica Bay Interceptor. On account of the flat topography, the sizes and gradients are calculated for velocities of 2½ feet per second when half full. This fixes the diameter at the 26th ward plant at 9 feet, which would increase to 12 feet 4 inches by the time it joined the Gravesend interceptor at Ocean Parkway. From this point, the interceptor would continue to the Coney Island pumping station with a diameter of 13 feet 3 inches passing under the Coney Island ship canal in a 66-inch cast-iron siphon.

The Gravesend interceptor would be 4 feet and the Shellbank interceptor 27 inches in diameter.

Jamaica Bay Pumping Stations. Owing to the increased depth between Flatbush Avenue and Ocean Parkway over that in Project O,* made necessary by the reversed direction of flow to the westward, the sewage from Caisson No. 3, Caisson No. 4 (Shellbank treatment plant) and Ocean Parkway would not have to be pumped. There would, therefore, be no pumping required at the main interceptors between the existing "Gravesend" pumping station at Bensonhurst and the present East New York treatment plant.

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*The recommended project for Jamaica Bay. See Chapter V.

To raise the sewage from adjacent territory there would be required the following pumping stations:

	East New York.	Paerdegat	Gravesend
Mean Flow..................	23.7 mgd.	14.3 mgd.	3.3 mgd.

It is assumed that the present building at East New York could be utilized for this purpose, in which case a new pumping station at Paerdegat would be the only one required for the Jamaica Bay Division.

Outlet. The submerged outfall tunnel would be 14 feet in diameter, laid to a crib in the Lower Bay.

Cost. The entire cost of construction, as outlined above, adequate to handle 250 mgd. sewage at first with provision for extension, is estimated at $20,984,000, and the annual charges, including interest and sinking fund, at $1,623,000.

Locally Placed Settling Tanks

This project contemplates treating the sewage of subdivisons 13, 14, 15, 24, 25 and 26 of the Lower East river, Hudson and Bay Division by independent sedimentation plants.

It is assumed that these six treatment plants would be located on what is now private property in the vicinity of the points of collection, and that marginal collecting sewers, tide gates and regulators would be provided.

At the points of collection the sewage would be passed through coarse cage screens and grit chambers and, where necessary, would be pumped so as to provide ample head for delivery.

For sedimentation modified Dortmund tanks would be provided, each hopper serving an independent unit 30x30 feet in size inside. These, being on private property, would not require the costly reinforced concrete necessary for Emscher tanks placed under the street surface.

The capacity of each tank when empty would be 11,500 cu. ft., giving a period of retention of 2 hours, and the depth from surface of sewage to the bottom of hopper, inside, would be 22.8 ft. As sludge would be drawn off daily there would be but little accumulation to shorten the above period of detention for the dry-weather flow. The maximum flow assumed would be three times the dry-weather flow, the surplus passing by storm overflows directly to the river.

The cost of land for the treatment plants is very difficult to estimate, but in order to cover the cost of such buildings as may exist on the lots taken for the purpose and their removal it is based on twice the highest price per front foot given for property that appears to be most suitable for the purpose, as stated in "Land Value Maps of the City of New York for 1911."* Reduced to prices per square foot these are, for:

Subdivision	13	14	15	24	25	26
Location	Roosevelt Street	Broome Slip	E. 14th Street	So. 5th Street	Hudson Street	Adams Street
Price per square foot.........	$12.00	$6.50	$5.50	$6.00	$6.00	$10.00

From the tanks the sewage would pass directly to the river by submerged outlets by one or more 36-inch pipes. Although the number and size of these would be determined by the flow to be expected from each plant, it has been deemed sufficient for the present purpose to provide one 36-inch outlet for each 12 million gallons per day of mean dry-weather flow.

Sludge and screenings would be taken daily by a sludge steamer of 1,000 tons capacity and dumped 4 miles E.S.E. of Scotland Light Vessel. The volume so disposed of is assumed as 5 cu. yds. per million gallons of sewage or 1,015 cu. yds. at 0.86 tons=873 tons per day. The distance traveled would be about 10 miles while calling at the six plants in the East river to fill and 50 miles from the Battery to the dumping ground and back. One vessel could accomplish this, working night and day, but to allow for contingencies two vessels would be provided each loading one day and dumping the next or else doing both on alternate days. In spite of some lost time or, it might be said, excess capacity of steamer, it probably would not be wise to provide for less with the certainty of a continuous increase of output which would soon necessitate more adequate provision.

Capacities are based on sewage volumes forecast for 1915, and the only additional cost for increased volumes will be for treatment plants and sludge disposal.

The cost of construction is estimated at $6,901,000 and the annual charges at $552,230.

TABLE XVII

DATA RELATING TO LOCALLY PLACED SETTLING TANKS

Sub-division	13	14	15	24	25	26	Total
Population, 1915........................	202650	264300	221000	310310	401500	23500	1423720
Mean dry-weather flow in mgd.............	42	25	32	34	66	4	203
No. tanks at 1.05 mgd.....................	40	24	30	32	58	4	188
Area req'd @ .04 ac. each..................	1.60	.96	1.20	1.28	2.32	.16	7.52
Cubic yds. sludge daily @ 5 per mg.........	210	125	160	170	330	20	1015
No. Outlet pipes @ 12 mgd. each...........	4	2	3	3	6	1	19
Cost of screening plants..................	$99800	$77000	$87100	$89800	$125100	$30800	$509600
Cost of land for plants....................	$40000	......	$19000	$15000	$10000	$25400	$109400

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*The Record & Guide Co.—Publishers.

Comparative Cost of Conveying 487 Million Gallons of Sewage Per Day from the Lower East River Section to Various Points for Disposal

Following are comparative estimates of the cost of conveying the forecast sewage entering the East River, amounting to 487 mgd., to different points for disposal. The costs of collecting the sewage to a pumping station near the Navy Yard or, in the case of disposal on Staten Island near Linoleumville, to the Battery, are not included in the estimates:

A. Intermittent discharge of crude sewage on outgoing tidal currents from an artificial island between Ambrose Channel and Coney Island.

Cost of construction	$22,120,000
Annual cost:	
Operation and maintenance	$1,338,700
Fixed charges	1,119,300
	$2,458,000

B. Continuous discharge of screened sewage from an artificial island between Ambrose Channel and Coney Island.

Cost of construction	$18,480,000
Annual cost:	
Operation and maintenance	$1,454,000
Fixed charges	935,000
	$2,389,000

C. Continuous discharge from an artificial island between Ambrose Channel and Coney Island after passing through Emscher tanks.

Cost of construction	$21,013,000
Annual cost:	
Operation and maintenance	$1,560,900
Fixed charges	1,063,300
	$2,624,200

D. Discharge from submerged outlet in the ocean off Rockaway Point after screening on Barren Island.

Cost of construction	$19,837,000
Annual cost:	
Operation and maintenance	$1,144,300
Fixed charges	1,003,700
	$2,148,000

E. Discharge from submerged ocean outlet off Rockaway Point after passing through Emscher tanks on Barren Island.

Cost of construction	$22,492,000
Annual cost:	
Operation and maintenance	$1,196,100
Fixed charges	1,138,100
	$2,334,200

F. Discharge to Rockaway Inlet after passing Emscher tanks and sprinkling filter on Barren Island.

Cost of construction	$26,331,000
Annual cost:	
Operation and maintenance	$1,743,900
Fixed charges	1,332,400
	$3,076,300

G. Discharge to Fresh Kills after passing Emscher tanks and sprinkling filters near Linoleumville, Staten Island.

Cost of construction	$30,058,000
Annual cost:	
Operation and maintenance	$1,626,600
Fixed charges	1,520,900
	$3,147,500

The above figures indicate that treatment by sprinkling filters either on Barren Island or Linoleumville would be far more costly than the other schemes, while the two least expensive are those involving screening only. If the point of disposal, in the latter case, were from an artificial island off Coney island

the first cost would be	$18,480,000
and the annual charges	2,389,000

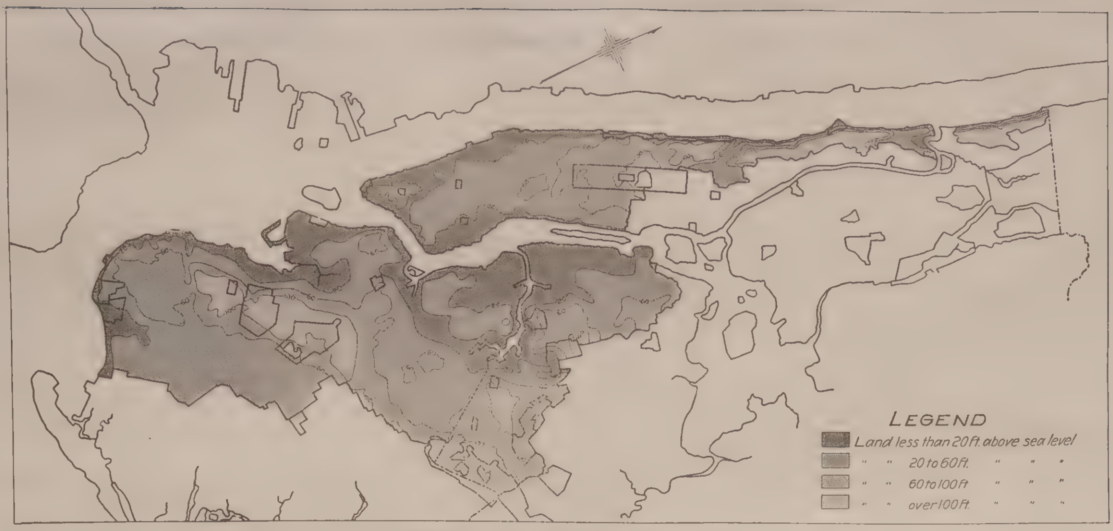
while if the discharges were in deep water off Rockaway Point

the first cost would be	$19,837,000
and the annual charges	2,148,100

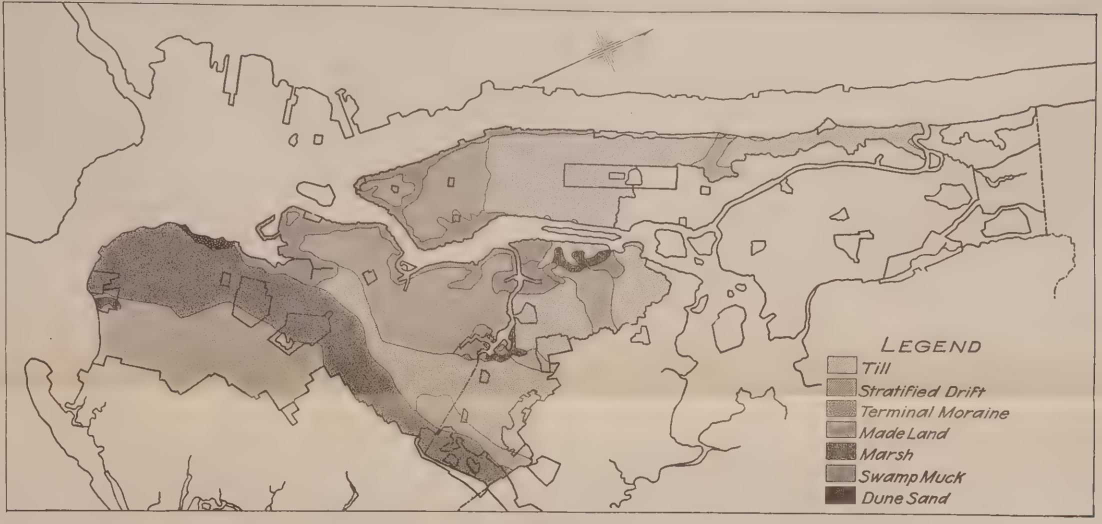
Recapitulation of Lower East River Projects

Aside from various plans which have been made for carrying the sewage of New York to sea or to a central point for treatment, there have been developed seventeen projects for the disposal of the sewage of the Lower East river.

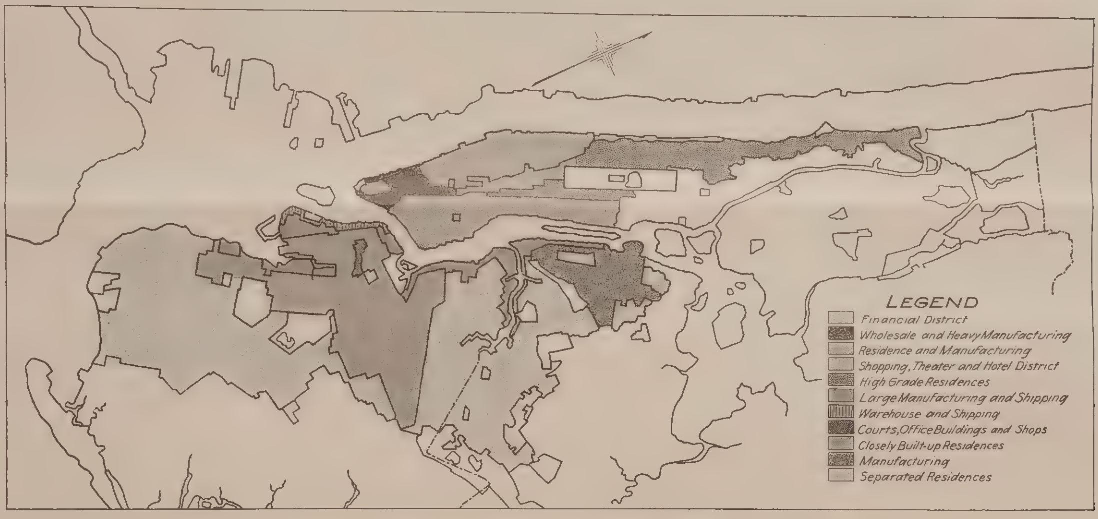
Of these projects, thirteen contemplated the complete removal of the sewage from



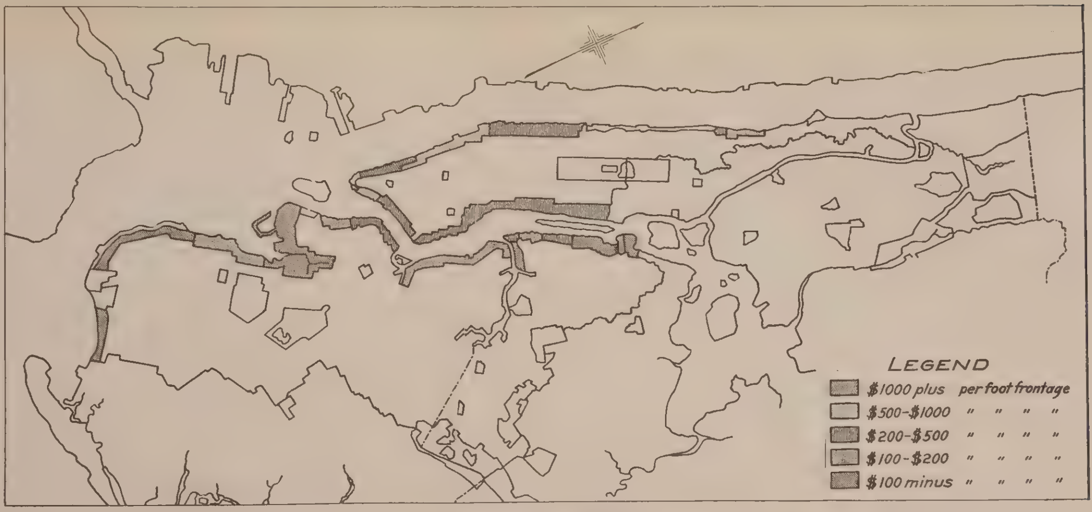
Elevations of Land Above Mean Sea Level



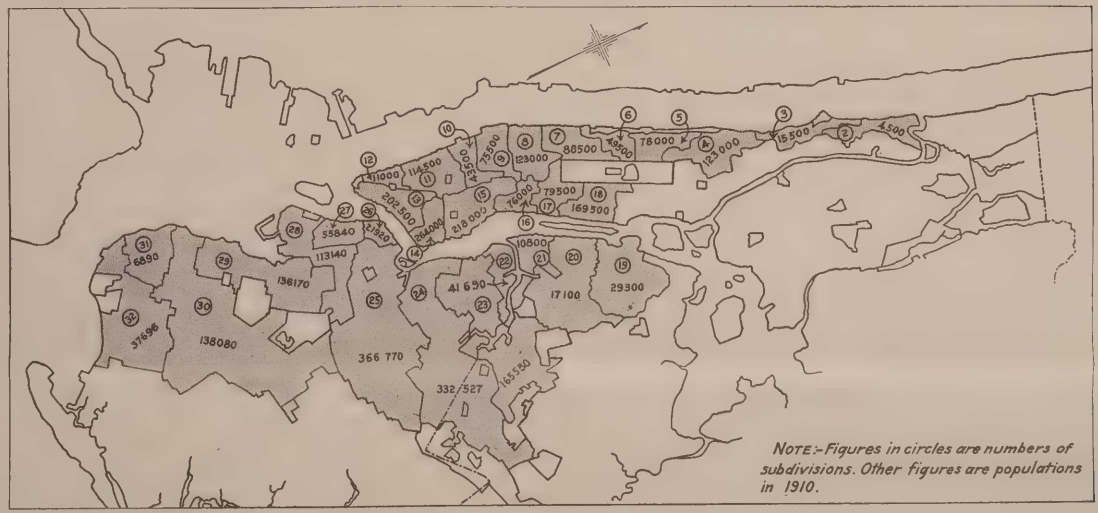
Surface Geology


LEGEND
Financial District
Wholesale and Heavy Manufacturing
Residence and Manufacturing
Shopping, Theater and Hotel District
High Grade Residences
Large Manufacturing and Shipping
Warehouse and Shipping
Courts, Office Buildings and Shops
Closely Built-up Residences
Manufacturing
Separated Residences

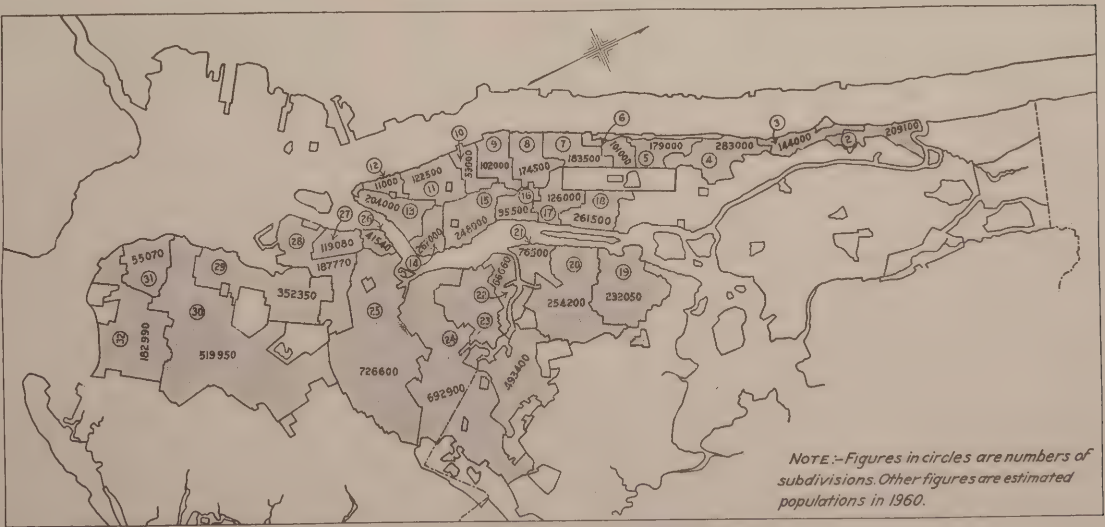
Distribution of Business and Residence Sections



Approximate Land Values



Subdivisions and the Population for 1910



Subdivisions and the Estimated Population for 1960

PLATE IX

Data Relating to the Lower East River, Hudson and Bay Division

this vicinity, two to an outlet crib in the Lower Bay, where it would be discharged continuously, without other treatment than coarse screening before pumping, and eleven to an artificial outlet island at the same location, the treatment to consist of fine screening in one case and of sedimentation in the other ten. These projects differed chiefly in the arrangement of interceptors and marginal sewers, territory included, and amount of sewage provided for. In two of these plans, removal to the ocean outlet island was contemplated as a final installation only, local treatment by fine screening being recommended as a first step in the construction. The project described in detail and recommended by the Commission and its consulting engineers is one of these.

Of the four remaining projects, two contemplated treatment by locally placed settling tanks, grit chambers and screens, with discharge of the clarified effluent into the Lower East river. Two others involved treatment by chemical precipitation on artificial islands, one located south of, or as an extension to, Blackwells Island in the Lower East river, the other off Red Hook, south of Governors Island, in the Upper bay.

The plan of intercepting the existing system of sewers was in all cases practically the same, either by marginal sewers feeding large interceptors, or by interceptors alone, paralleling the water-front, excepting in Projects VIII and IX, in which the laterals were intercepted inland, above the influence of the tide, and the territory between the interceptor and water-front was resewered to drain towards the former.

Only one project, No. I, dealt with both the Harlem river and Western Jamaica sewage in addition to that of the Lower East river, while one other, No. III, dealt with the Western Jamaica sewage. Most of the ocean island outlet projects contemplated, as a final installation, the removal of the sewage of the Western Jamaica subdivision.

The quantities of sewage provided for varied from 133 to 987 mgd. The smaller figure is for Project XIII, first installation, consisting of the screening and subsequent discharge into the East river of the sewage from subdivisions 13, 14 and 15 in Manhattan, and 24 in Brooklyn. The second figure is for Project I, consisting of the removal to sea of the sewage tributary to the East river below Hell Gate, subdivisions 13 to 26, inclusive, with the Wards Island flow and that of the Western Jamaica subdivision. The costs ranged from $2,506,550 for Project XVI, consisting of screening and discharging from local plants the sewage of subdivisions 13 to 15 in Manhattan and 24 to 26 in Brooklyn, to $42,824,000 for Project I, as described above.

CHAPTER VII

FORM OF ADMINISTRATION RECOMMENDED FOR THE PROTECTION OF NEW YORK HARBOR AGAINST EXCESSIVE SEWAGE POLLUTION

INTRODUCTORY

In its report issued April 30, 1910, the Metropolitan Sewerage Commission described the conditions of sewerage and sewage disposal for the metropolitan area of New York and New Jersey and showed that the disposal of the sewage produced in this large territory was without control or regulation of any kind. The total extent of land and water included in the district was about 700 square miles. The population in 1910 was about 6,000,000 and the number of municipalities exceeded 80. Every city and town was permitted to collect and dispose of its sewage in such quantity and in such manner as it saw fit. It was customary to discharge into the nearest arm of the harbor with little or no regard to the volume of diluting water available at the point of outlet and without respect to the nuisance or injury to health which might be produced before the sewage was finally assimilated by the forces of nature.

Lack of administration over the discharge of sewage had resulted in grave sanitary evils not only to the municipalities, but elsewhere. Some of the sewers had been badly designed and constructed. In a large number of instances, the outlets were flooded by the tides, in consequence of which the sewage was driven back and afforded an opportunity to deposit and putrefy. The discharge of sewage usually took place into inadequate currents, with the result that many of the cities and towns polluted their own shores and waterways to a serious extent. With the increasing quantities of sewage which the rapidly growing population would produce, the harmful consequences of the chaotic methods of sewage disposal would be certain to multiply.

In the Commission's opinion, the problem of disposing of the sewage of the metropolitan district should be considered without regard to State, municipal or other political boundaries. The metropolitan area was tolerably well defined by topographical conditions and by the distribution of population and the various parts of this territory were so related that the sewage of no section could be disposed of without reference to the health and welfare of others.

The harbor waters represented a great financial asset so far as sewage disposal was concerned, inasmuch as it was evident that large quantities of sewage could be discharged into the harbor without harmful consequences if the sewage was prepared for this method of disposal by suitable treatment and the discharges were arranged to take place under advantageous circumstances.

The Commission recommended that an interstate metropolitan district and commission be established for the central regulation of the disposal of the sewage of that part of New York and New Jersey whose natural drainage was immediately tributary to New York harbor.

Since the report of 1910 was issued, further study has been made of the form of administration necessary for the metropolitan area of New York and New Jersey and the results of this study are set forth in the following pages.

In addition to the form of supervisory control which it will be desirable to establish over the disposal of sewage in the metropolitan district, provision should be made for a proper administration of such works of main drainage and disposal as are required. No single connective system for the collection and disposal of the sewage of the entire territory is required. Any plan for collecting all the sewage to a central point for disposal would be extravagantly costly and would be unnecessary. The fundamental principle which should govern the design of the main drainage and disposal works required should be to make full use of the digestive capacity of the harbor waters and the reasonable application of this principle requires that the sewage after proper preparation shall be discharged at a large number of points throughout the harbor. This plan will necessarily require the construction of a series of systems of main drainage and disposal, rather than a single united system. Careful attention should be given in each case to the operation of all the works and the several units, of which the composite whole is made up, should be most carefully and intelligently coördinated.

In some instances the main drainage works for the disposal of the sewage of a large part of the territory should lie within the limits of a single municipality; in other cases various municipalities should combine.

By far the most important works, as well as those of the most immediate necessity will be required for the City of New York. This fact became evident early in the Commission's investigations and since the 1910 report was made a very large share of the Commission's attention has been given to the design of the works required by that city.

It will be possible and desirable for the works of main drainage and sewage disposal for New York to be confined to that city and yet physically united with the main drainage structures which may be required in the adjoining territory. In another report, the Metropolitan Sewerage Commission has described the works which New York should construct. In the following pages is given the plan of administration which the Commission considers desirable for the construction and maintenance of the necessary structures.

QUESTIONS RAISED BY THE LEGISLATURE AND ANSWERS

The Act of Legislature which provided for the creation of the Metropolitan Sewerage Commission submitted four principal questions for the Commission to investigate and express an opinion upon.

The act asks:

1. Whether it is desirable and feasible for New York City and the municipalities in its vicinity to agree upon a general plan or policy of sewerage and sewage disposal which will protect the waters of New York bay and vicinity against unnecessary and injurious pollution by sewage and other wastes?

2. What methods of collecting and disposing of the sewage and other wastes which pollute, or may eventually pollute, the waters contemplated in this act are most worthy of consideration?

3. Whether it is desirable to establish a sewerage district in order properly to dispose of the wastes, and adequately protect the purity of the waters contemplated in this act, and, if so, what should be the limits and boundaries of this sewerage district?

4. What would be the best system of administrative control for the inception, execution and operation of a plan for sewerage, and ultimate sewage disposal, of a metropolitan sewerage district; whether by the action of already existing departments and provisions of government, by the establishment of separate and distinct sewerage districts and permanent commissions in each State, by one interstate metropolitan sewerage district and commission to be established by agreement between the two States, this agreement if necessary to be ratified by Congress or by other means?

The Commission finds that:

1. It would not be possible to protect the waters of New York bay and vicinity by inter-city agreement. There are about 80 municipalities concerned and the subject would be beyond their capacity to regulate properly. Existing departments and provisions of government cannot appropriately nor adequately deal with this question.

2. Extensive main drainage works are required for the protection of the harbor, such as have been built for many other large cities and towns, the essential features of the necessary structures being intercepting and collecting stations, where the sewage can be purified to a greater or lesser degree, depending on the requirements, and finally discharged into the tidal water.

3 and 4. There should be two forms of administration provided for. One of these should be of a general and supervisory nature and have jurisdiction over the entire metropolitan territory of New York and New Jersey. The other should be for the construction and maintenance of the works.

The duties of the supervisory body should be to compel cities and parts of cities within the district to carry out such works as may be necessary for the common welfare and to improve those parts of the harbor which threaten to give rise to nuisance of local character. Other construction work should be carried on as now, except where it can be more efficiently and economically done by special commissions, boards, departments or bureaus.

I. AN INTERSTATE SUPERVISORY COMMISSION

The supervisory commission should be established by acts of the Legislatures of New York and New Jersey, these acts to be confirmed by Congress. There should be a sewerage district under that commission.

The most desirable limits for the sewerage district would include a territory of about 700 square miles about half of which would be in New York and about half in New Jersey. Within this territory there was in 1910 a population exceeding 6,000,000 people. At the rate of increase which has been maintained for some years the population will exceed 11,500,000 by the year 1940. The quantity of sewage produced in 1910 was about 765,000,000 gallons per 24 hours and it has been estimated that there will be over 1,700,000,000 gallons produced by the year 1940.

Within the territory proposed for a metropolitan sewerage district no sewage is disposed of at the present time without producing a nuisance or serious risk of nuisance. There is no central sanitary control over the discharge of sewage by the national or state governments. The difficulties to be overcome in disposing of sewage are of unusual difficulty and complexity owing to the great extent of the territory, the large population and the many hydrographic, sanitary and economic questions which must be considered in the localities concerned.

The present condition of the harbor, the rapidly increasing quantities of sewage which are being discharged into it and the difficulty and cost of preventing excessive pollution make it evident that the time has arrived when the two States should place the protection of the waters against sewage in the hands of a single authority. It will be regrettable and expensive, not to say dangerous, if the existence of the State boundary line which runs through the center of the harbor is allowed to prevent the centralization of proper control over the sewage question.

The duties of an interstate sewerage commission for the metropolitan district of New York and New Jersey should be to require the construction of such works of main drainage as are needed to permanently improve and protect the waters of New York harbor and all the waters within the metropolitan sewerage district. The commission should not be charged with the duty of constructing local sewerage, main drainage or disposal works, but should have advisory authority over their design in so far as they may affect the condition of the harbor. The sewers needed for the purely local purpose of carrying the sewage from the houses to the water front or other point for discharge should be designed by the several municipalities. The main drainage or arterial sewerage systems needed to collect the sewage from the local sewers and carry it to the central points for disposal should be designed and built by the several municipalities acting conjointly, or by district sewerage boards created for the purpose of disposing of the sewage of considerable portions of the metropolitan district. Such purification works and outfalls as are required should be constructed by these sewer authorities or the district sewerage boards.

The central board having jurisdiction over the metropolitan district should be composed of representatives or delegates from the States of New York and New Jersey and the United States Government. The duties of the central commission should be to prepare a general and normal standard of cleanness for the natural and artificial water courses within the metropolitan district, including, if deemed necessary, special standards for different places. Standards of different degrees of severity for the different parts of the harbor may be found desirable, depending upon the uses to which the water is put and according to the quality and quantity of the sewage discharged, the topographical conditions and consequently the cost to the municipalities of producing an effluent of good quality. From a comprehensive standpoint it may be more economical to demand compliance with a very high standard of purity for the sewage of some communities, rather than with a uniform standard from all where, for example, the local circumstances seem to justify such an exception.

There should be considered not only the particular part of the harbor where the sewage is discharged, but those other parts which may be indirectly affected. There should also be considered the total quantity of sewage produced as well as the ratio which the sewage bears to the water into which it is discharged, and account should be taken of the possibility that objectionable deposits of sludge may occur.

The central commission should determine where discharges of sewage may, and may not, take place and pass upon the quality of the discharging sewage liquor. The central commission should insist upon plans being furnished by cities or drainage boards representing parts or groups of municipalities for a progressive scheme of sewage disposal and should encourage the combination of cities and towns in the formation of drainage boards when, in the judgment of the central commission, such boards are needed in order to make and carry out proper plans for the sanitary conservancy of the harbor waters.

There should be drawn up a code of instructions or regulations covering, as far as may be, the general requirements of the central commission. There should be prepared standard specifications and a set of uniform designs with the object of making as uniform as practicable and more efficient the construction and maintenance of sewers and other appurtenances.

The central authority should be authorized to carry on such experiments and investigations as may be necessary in order to increase the existing knowledge of the principles of sewage disposal as they relate to the metropolitan territory. It should be their duty to make such studies of the harbor as may be necessary in order to form an authoritative opinion concerning dangers to health and risk of nuisance.

Power should be given to the central commission to require accurate reports to be rendered by local authorities as to the volume and quality of sewage produced, progress and cost of sewerage and sewage disposal works, value of property, character and extent of the industries and the financial status of the municipalities.

The central commission should have power to enter upon all lands and property in the district at any time, and without notice, for the purpose of inspecting the local sewers, main drainage and disposal works and the sewage and for taking samples anywhere and in any part or parts of the local and main drainage and disposal works. Authority should also be given to require that all works connected with the collection and disposal of the sewage be so built as to permit samples being taken and gaugings of the flow to be determined except in those cases in which such construction would involve unreasonable cost. The central commission should be empowered to make regulations as to the treatment of storm water as well as sewage.

The central commission should have power to administer oaths and subpoena witnesses. It should be their duty to prepare and publish reports in regard to the progress of the work being done in the district to effect a sanitary disposal of the sewage together with a statement of the size and distribution of population, the condition of health and the sanitary quality of the harbor waters.

Also it should be the duty of the interstate commission to require the employment of such methods of sewage disposal as will reasonably protect New York harbor and the other waters in the metropolitan district against excessive sewage pollution. This duty should be discharged with due regard to expense and the extent and nature of the existing evils. The work should proceed by degrees. The central commission should deal first with the worst offenders, which will probably be found to be the largest cities and where the cost of substantial improvement will be least. By insisting upon comprehensive plans for sewage disposal being made at an early day, a program of sewer building which can be carried out as the growth of population and other circumstances require will be adopted, rather than definite plans for immediate and complete construction.

II. A CONSTRUCTING COMMISSION FOR NEW YORK

With respect to the form of administration which should have charge of the construction of the engineering works for New York, the following recommendation is made.

The works should be built by a special commission. The sewage problem is essentially one problem and not an aggregation of more or less loosely related parts. The pollution is not only local but general, and the system which is to correct the conditions should be one general system. Such divisions of the work as are necessary should depend chiefly upon topographical conditions and the facilities which the various sections of the harbor afford for the assimilation of sewage, and not upon political boundaries. The works would be of such magnitude that they should receive the concentrated attention of a special board or commission.

The creation or designation of a central commission to construct main drainage and sewage disposal works would be in accordance with precedent, as witness the provision made for constructing New York City's water supply and rapid transit systems, the metropolitan sewers of Boston and vicinity, the main drainage system of the London County Council, the drainage and disposal works of Birmingham and neighboring municipalities, the sewage and drainage works of the Emscher Valley in Germany, the trunk sewer system of the Passaic Valley in New Jersey and the sewage disposal works of Chicago.

In some cases, but not all, the main drainage commissions are temporary in character and when the work for which they have been created is completed, they go out of existence and the result of their labor is turned over to some permanent and usually pre-existing department.

For a special commission to be created for the main drainage of New York, special legislation would doubtless have to be secured at Albany. This legislation could, with advantage, be modeled to some extent upon that of the Catskill Water Board.

The work of constructing the main drainage works required for New York could be placed in the hands of the New York Water Board, the powers and duties of that body being appropriately altered by legislative act for that purpose. The Water Board has a large engineering and clerical organization. It is nearing the completion of its undertaking. Its engineering works have been hydraulic in character and of magnitude commensurate with the main drainage and sewage disposal plants. The Commission is already in existence and possesses machinery for the conduct of its affairs. These are among the obvious advantages which could be gained by placing the main drainage works in the hands of the Water Board for construction.

If the works were built by a central commission, that commission would be as responsible and responsive to one section of the city as to another. Security in this respect would not depend upon harmony and co-operation, as it would if the construction of the works were placed in the hands of the boroughs. Being for the benefit of New York harbor and the city as a whole, questions of local interest should be made subservient to those of the general welfare and this could best be secured by a board composed of men representing the city at large. The undivided time and attention of a central commission being given to the subject for which it was created, there would be no lapse of interest or lack of attention to the work.

Borough construction, however appropriate it may be for local drainage, the object of which is to improve the city's occupied land, is not so suitable for main drainage and sewage disposal works whose purpose it is to improve and protect the city at large and its general waterways. Harbor work should be, and generally is, strongly centralized, as, for example, dredging and dock building.

If the work were placed in the hands of a central commission, no time or energy would be lost in overcoming the inertia of a borough whose duty it was to construct works chiefly for the benefit of other boroughs, or in weighing the relative merits of rival schemes presented by the several boroughs for mutual improvement, or passing judgment upon measures intended primarily for local benefit.

The construction of a main drainage and sewage disposal system requires a high degree of scientific and technical skill. A central commission with a single corps of technical assistants would be less expensive for the city to maintain than a separate corps in each borough. The experience gained in constructing and operating the works in one locality should be completely available for the benefit of all. This would be automatically provided for in a central constructing commission.

In arriving at a conclusion upon the subject of administration, the commission had the benefit of the views of a number of citizens who, from official position or other practical experience, are particularly well qualified to advise. The number included Ex-Mayors Seth Low and George B. McClellan, also Messrs. Lawson N.

Purdy, Robert W. DeForest, Henry R. Towne, E. H. Outerbridge, Charles Strauss and George L. Rives.

The work of the Metropolitan Sewerage Commission throughout has been based upon the theory that the problem of disposing of New York's sewage without harm to the public health and welfare was city-wide in scope, demanding comprehensive solution and strongly centralized control.

It is the opinion of the Commission that the construction and maintenance of the works should be placed in the hands of a special commission existing for that purpose. It is possible that where parts of the system would be situated wholly within a borough, it might be desirable to turn those parts over to that borough to operate under the regulation and control of the central commission.

If a commission were created to construct such sewerage works as New York requires, it should take over the effects of the Metropolitan Sewerage Commission, make the final detailed plans and estimates required and, after duly submitting its projects to the Board of Estimate for approval, proceed with the construction.

In this way the city would be certain to obtain the benefit of such works as would be needed and without unnecessary loss of time or expenditure of money.

There would be no delay for investigations of an academic or unnecessary character. The city would be protected against the extravagance of building works long before or long after they were needed.

The detailed planning being in the hands of the constructive body, responsibility for obtaining practical results at a minimum of expenditure would be concentrated.

In preparing a bill for the new commission, it will be desirable to be guided by Chapter 724 of the Laws of 1906, which is the basic legislation for the Catskill Water Board. That act covers much of the material which will be required on the organization of an independent board of main drainage and sewage disposal and hence furnishes material which, having been tested, may safely be followed. It also furnishes much which by a similar test it would be wise to avoid. General heads for the bill follow:

1. Take over, continue and extend the work of the Metropolitan Sewerage Commission.
2. Make such detailed investigations, including surveys and borings, as may be necessary to make contract plans and estimates for the construction of a system of main drainage and sewage disposal for New York City.
3. Prepare the necessary plans and estimates.
4. Construct the main drainage and sewage disposal works required after they have been duly approved by the Board of Estimate and Apportionment.

5. Operate the works after construction or, where parts are situated wholly within a borough, perhaps turn those parts over to that borough to operate under the regulation and control of the central commission.

6. The commission should be appointed by the Mayor and report to him.

7. Authority should be given for the employment of an engineering and clerical force and such other assistants as may be necessary for the performance of the duties specified.

8. Appropriations for the work to be done should be made by the Board of Estimate and Apportionment in accordance with provisions of the Catskill Water Board.

9. The coöperation and assistance of the Sewer Bureaus of the city should be given as, and when, requested by the new commission.

10. The work of the new commission should not overlap that of the Sewer Bureaus as provided by the city charter except where unavoidable in providing for the main drainage and disposal of the city's sewage.

11. Corporate stock of the City of New York should be authorized to be issued by the Board of Estimate and Apportionment without the concurrence or approval of any other board or public body, in accordance with section one hundred and sixty-nine of the Greater New York Charter, in order to provide the means for carrying out the provisions of this act. All payments from the sale of such corporate stock should be made upon proper vouchers in accordance with the laws and regulations now in force for the payment of money by the Comptroller of the City of New York.

12. Authority should be given for the acquirement of such property as may be needed for the construction of the main drainage and disposal works after due and proper authorization has been given.

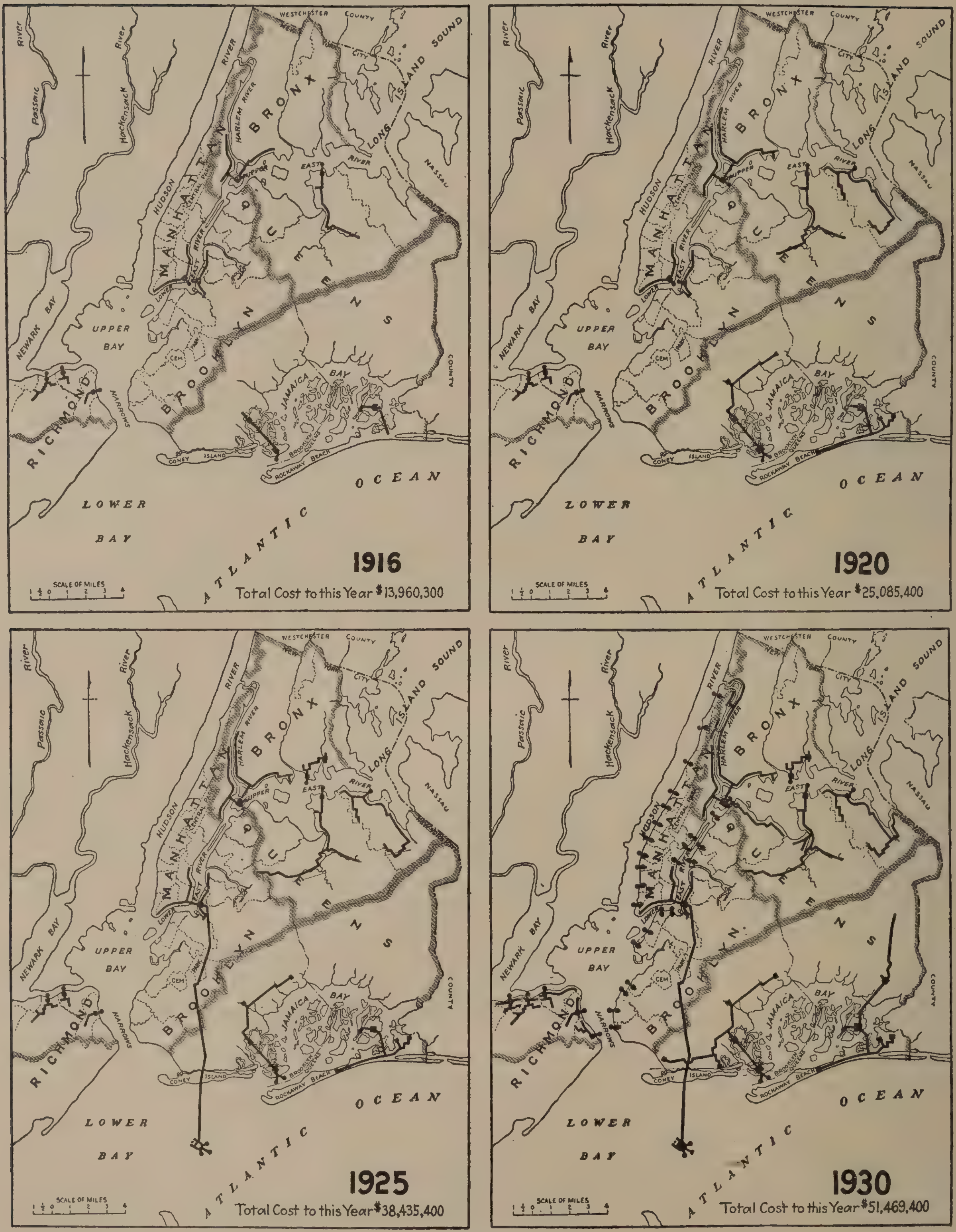


PLATE X

Order in which it is suggested that the works be built

PART III

Reports of Experts Consulted by the Commission

PART III

Reports of Experts Consulted by the Commission

CHAPTER I

CRITICAL REPORTS ON THE COMMISSION'S WORK WITH SPECIAL REFERENCE TO THE MAIN DRAINAGE SYSTEM PROPOSED FOR THE PROTECTION OF THE LOWER EAST RIVER AND OPINION OF THE COMMISSION WITH RESPECT TO THESE REPORTS

I

INTRODUCTORY

Of the five experts whose reports are here published, all are in agreement with the Commission in the opinion that main drainage and sewage disposal works are required for the protection of the Lower East river and that the time has come to begin their construction.

Three of the five are convinced that nothing short of the removal of a large part of the sewage naturally tributary to this part of the harbor will produce the improvement needed; the other two consider that partial purification and local discharge will be sufficient, at least for many years.

The Commission's opinion is that the removal of not less than 200 million gallons of sewage per twenty-four hours to an ocean outlet is a project to which the city should look forward as an early necessity and it has provided general plans and estimates to accomplish this result. The Commission recommends that the ocean island project be carried out in progressive stages, the first of which would be the collection of the sewage to a number of central points for screening and local discharge through submerged outlets. If experience shows this method of disposal to be insufficient, the local outlets would be discontinued and the sewage would be carried to sea. With this method of procedure, the Commission and its advisers are in complete accord.

The reports are so important that the Commission publishes them here in full. To facilitate an understanding of the principal subjects dealt with, particularly the oxygen standard and the project for the relief of the Lower East river, it has seemed desirable for the Commission to preface the reports with an introductory note, a digest of the reports and the Commission's opinion upon the main points which the experts have discussed.

THE OXYGEN QUESTION

All who possess an adequate and unprejudiced knowledge of the harbor recognize that (1) the water is now inadmissibly polluted, and is especially foul in some locations; (2) extensive works of main drainage and sewage disposal are required in order to improve and permamently protect the harbor; (3) the construction of the necessary works should be placed in the hands of a central constructing body; (4) the system of main drainage and sewage disposal which the city requires should be begun at once and added to gradually as their necessity is recognized; (5) the principle of development should apply not only to the gradual extension of the collecting system, but to the efficiency of the method of disposal; (6) the requirements of the future will be more exacting than those of the present in regard to the degree of cleanness which should be maintained in the waterways; (7) the increasing quantities of sewage will make the realization of any standard increasingly difficult, and (8) in disposing of the sewage the digestive capacity of the water for sewage matters should be utilized to the fullest extent compatible with a due regard to the public health and welfare.

In the Commission's opinion it is not indispensable that any pronouncement as to oxygen should be made in the standard of cleanness, since, if the remaining specifications of the standard are faithfully carried out, there will be enough oxygen in the water to meet all reasonable requirements. A limit to the exhaustion of the oxygen is desirable merely as an amplification of the other specifications of the standard. The oxygen which exists in dissolved form in the water is a convenient measure of the relative intensity of pollution and nothing more. It is superior to other measures of pollution in that it is definite and can readily be made and interpreted. Resting upon accurate analysis, it is independent of such sources of error as are inseparable from tests which depend upon personal judgment. It is not practicable to describe the appearance or odors of pollution with anywhere near the accuracy with which the amount of dissolved oxygen can be expressed.

With reference to its definiteness and adequacy, the oxygen test is probably the best chemical criterion to be found. It has been used by the Commission almost to the exclusion of the far more elaborate and difficult determinations of nitrogen which were formerly considered to be indispensable as a means of accurately measuring the extent to which a natural body of water was polluted. It has recently come into favor with other investigators, a notable example of its value being afforded in the Eighth Report of the Royal Commission on Sewage Disposal of Great Britain, issued in 1913. But the importance of the oxygen test, like any other measure, depends upon its application; and since experience now shows that it may be misunderstood, even by experts, it may be omitted.

Omitting the reference to oxygen,* the Commission's standard of cleanness is as follows:

1. Garbage, offal or solid matter recognizable as of sewage origin shall not be visible in any of the harbor waters.

2. Marked discoloration or turbidity, effervescence, oily sleek, odor or deposits, due to sewage or trade wastes, shall not occur except perhaps in the immediate vicinity of sewer outfalls, and then only to such an extent and in such places as may be permitted by the authority having jurisdiction over the sanitary condition of the harbor.

3. The discharge of sewage shall not materially contribute to the formation of deposits injurious to health or navigation.

4. The quality of the water at points suitable for bathing and oyster culture should conform substantially as to bacterial purity to a drinking water standard. It is not practicable to maintain so high a standard in any part of the harbor north of the Narrows, or in the Arthur Kill.

Project for the Protection of the Lower East River

It is proposed to carry about 200 million gallons of sewage from those parts of Manhattan and Brooklyn which are naturally tributary to the Lower East river to an island to be built in the ocean about 3 miles from shore. The rest of the sewage tributary to the Lower East river and that naturally flowing to the Upper bay and the Hudson would be passed through grit chambers and screens and discharged at the bottom of the neighboring channels well out from shore.

The ocean island project would collect the sewage by intercepting sewers running along the water-front and passing by a siphon from Manhattan to a point near the Brooklyn Navy Yard. A pumping station would force the sewage through a tunnel to the island where, after passing through settling basins, the sewage would be discharged into the surrounding water under such circumstances as would insure prompt diffusion and digestion. The Commission's preliminary studies indicate that the total cost of construction for the ocean island outlet would be about $21,466,000, including $4,072,000 for the Jamaica bay division. The fixed charges would be about $1,086,000, allowing $206,000 for the Jamaica bay division. The total maintenance and fixed charges were estimated at $1,598,000, including $286,000, chargeable to the Jamaica bay division. The construction of the island has been estimated at $615,000.

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* Except in the immediate vicinity of docks and piers and sewer outfalls, the dissolved oxygen in the water shall not fall below 3.0 cubic centimeters per liter of water. (With 60 per cent. of sea water and 40 per cent. of land water and at the extreme summer temperature of 80 degrees F., 3.0 cubic centimeters of oxygen per liter corresponds to 58 per cent. of saturation.) Near docks and piers there should always be sufficient oxygen in the water to prevent nuisance from odors.

Modifications of the ocean island project, as first proposed, have shown the possibility of materially reducing the cost without impairing the effectiveness of the scheme of protection for the Lower East river. In accordance with these modifications, a large amount of storm water originally provided for would be excluded from the works and provision would not be made for receiving the Jamaica bay sewage. The sizes of the interceptors and tunnel and of the settling basins would thus be reduced and the cost could be cut down to about $14,000,000, and the yearly cost to about $1,000,000. If it were thought desirable to build the works piecemeal, it would be feasible to construct the interceptors and carry the sewage to the two centrally located points on the Lower East river which would ultimately be connected by an inverted siphon. Here screens could be employed until such time as the need of entirely removing the sewage from the Lower East river territory became recognized. After passing through the screens, the sewage would be discharged into the water of the Lower East river. When it became necessary to complete the scheme, there would be left for construction the inverted siphon between Manhattan and Brooklyn, the pumping station to force the sewage to the ocean, the force main and the island. Reduced to these lowest terms in order to show how the works could be constructed gradually, the first cost would be $4,000,000.

The ocean island project is not intended to relieve the Lower East river of all the sewage which is now tributary to that stream, much less that which will be tributary in the future. Its object is merely to remove a sufficient part of the burden of pollution to permit the water to assimilate the remainder without offense. The Commission's island project applies to only six of the fifteen sub-divisions of Manhattan and Brooklyn which are tributary to the Lower East river. These six produce 203 of the 288 million gallons of sewage which it is estimated is now (1914) flowing into the East river between Hell Gate and the Battery. By the year 1960 the total quantity of sewage entering will be at least 500 million gallons per day and at that time the ocean island project, if in operation, will be taking less than one-half of the total contribution.

In addition, there will be discharged from the Wards Island works or, if these are not built, from some part of the Harlem territory 302 million gallons of sewage per day by the year 1960. Therefore, if the ocean island is built, there will be discharged into the Lower East river the sewage just referred to as the Wards Island effluent, amounting to 302 million gallons and the effluent which can receive no more than screening from the rest of the East river parts of Manhattan and Brooklyn, 215 million gallons in 1960, amounting to upwards of 500 million gallons per day.

The ocean island plan was made after carefully considering a number of alternative methods of disposal, including (1) treatment in works situated on the shores of the territory from which the sewage was derived and the subsequent discharge of the effluent into the adjacent waters; (2) removal to Wards Island at Hell Gate for treatment and discharge; (3) pumping to Staten Island and treatment at that point with discharge into the Arthur Kill or by means of a tunnel through Staten Island into Lower New York bay; (4) conveyance through a force main to Barren Island, treatment at that point and discharge into Rockaway Inlet or into the ocean off Rockaway Point.

For that part of the sewage which is naturally tributary to the Lower East river, Hudson and Bay not otherwise provided for, the Commission recommends screens and grit chambers as the treatment most appropriate before discharge at the bottom of the nearest deep tidal currents. The exact number and location of the screening stations would depend upon local detailed surveys and other information which it has been unnecessary to obtain before the work is put in hand for construction. Careful studies have been made of all typical situations which show the essential character of the work to be done and the difficulties to be overcome. It is estimated that the first cost of a grit chamber and screening plant will average about $100,000, and the annual charges about $5,000, where pumping is not required. The total number of stations would probably not exceed 20.

In many respects the making of plans for the disposal of the sewage of that part of New York draining naturally to the Lower East river has been the most difficult part of the Commission's work. The large volume of sewage to be dealt with, the relatively small body of water into which it is now discharged, the necessity for keeping the river clean enough to answer the requirements of the heavy shipping and of the dense population situated upon the shores and the absence of suitable areas of low-priced land within many miles have made the preparation of a plan of sewage disposal for this territory particularly difficult.

Instead of carrying out the project with its interceptors, siphon, pumping station, main, island and settling basin disposal plant as one undertaking, the Commission recommends that only the first step in the execution of this comprehensive plan be undertaken immediately.

The works to be taken in hand at first would be, for Manhattan, an intercepting sewer running along the Manhattan water front from the Battery at the south and 26th Street at the north to a point near Corlears Hook, where a screening and pumping station would be located. The screens would operate upon the most efficient principle for fine screens. The sewage, after screening, would be discharged well out from shore at the bottom of the river through multiple outlets.

On the Brooklyn side, the sewage would be collected by an interceptor from Classon Ave. at the south to Newtown Creek at the north to a point near South 5th Street, where it would be passed through screens like those on the Manhattan side of the river and pumped through submerged outfalls lying on the river bottom to a distance sufficiently far from shore to insure immediate and thorough diffusion.

The sewage from the rest of the Lower East river territory in Manhattan and Brooklyn would be collected for screening and discharge probably to as many points as there were subdivisions or principal drainage areas. If, after the foregoing works shall have been carried out, it be found necessary to afford further protection to the Lower East river, the city could proceed to construct an inverted siphon to carry the sewage of lower Manhattan beneath the East river to the Brooklyn shore where, after joining the sewage from the screening plant at South 5th Street, it would be pumped to sea by means of pumps and a force main to be constructed for this purpose.

In this stage of the development of the project, the sewage would be discharged through multiple outlets arranged from an outlet island. The sewage would have been screened and perhaps aerated and disinfected before arriving at the island.

In the final development of the project, the treatment works, presumably consisting of settling basins, would be built. The sewage would pass through the settling basins and receive such additional treatment as might be necessary before discharge.

In the systematic and gradual development of the ocean island project as here indicated, it will be possible for the city to proceed without large expense in any year and to test by actual experience the necessity for each step before it is taken. In case it is not thought necessary to proceed in this deliberate manner, it will be possible to combine the two last stages and build the siphon between Manhattan and Brooklyn, the pumping station, force main and island works at one time.

The gradual construction of the outlet island, in accordance with the plan here proposed, would make it unnecessary to sacrifice any considerable part of the works constructed in any stage by reason of their becoming useless in the succeeding stages of development.

II

SYNOPSIS OF THE EXPERTS' REPORTS

Reports of Messrs. Fowler and Watson

Before arriving at an opinion as to the best solution of the Lower East river problem, the Commission laid its alternative schemes before two prominent and unprejudiced sewage experts, Dr. Gilbert J. Fowler, of Manchester, and Mr. John D. Watson, of Birmingham. These experts were requested to come to New York and study the data which had been collected by this Commission, remaining long enough to become personally acquainted with the situation and to weigh the relative merits of the alternative plans which had been made. They came to America separately and made their studies independently of one another, although while still in New York and later in England they met and exchanged views. Messrs. Fowler and Watson are acknowledged leaders in the science and art of sewage disposal and are known throughout Europe and America not only for their professional attainments in this field, but for their broad experience and sound judgment in dealing with new problems. Each has a large consulting practice and has repeatedly been called beyond the confines of his country to furnish advice on the disposal of municipal sewage.

Dr. Fowler, a chemist, is a Doctor of Science, Fellow of the Institute of Chemistry, Fellow of the Royal Sanitary Institute of Great Britain and author of numerous reports, papers and contributions to the subject of sewage purification. He has been a contributor to the work of the Royal Commission on Sewage Disposal, whose published researches constitute the most exhaustive and valuable reference works on sewage in any language. The disposal works of Manchester, England, of which Dr. Fowler is chemist, have been developed under his direction to a high point of efficiency. These works include screens, settling basins, contact beds, sludge storage reservoirs and steam vessels for transporting the sludge to the open sea.

Mr. John D. Watson, who is a member of the Institute of Civil Engineers of Great Britain, a Fellow of the Royal Sanitary Institute and President of the Institute of Sanitary Engineers, is a consulting engineer. His published addresses reviewing the status of sewage disposal methods are among the most notable papers which have appeared upon the question. Like Dr. Fowler, he has been identified with the work of the Royal Commission on Sewage Disposal. Mr. Watson is the Chief Engineer of the Birmingham, Tame and Rea District Drainage Board and in this capacity has charge of the sewage purification works for Birmingham and various cities in its vicinity, works which are as large and efficient as any of their kind. Originally consisting of farm lands, where the sewage was taken for disposal in the hope of utilizing its manurial properties, the Birmingham works have been rebuilt by Mr. Watson in accordance with modern scientific principles and include settling basins, sludge-digesting tanks, supplementary settling basins, percolating filters, screens and sludge-drying beds.

The reports of Messrs. Fowler and Watson, therefore, approach the subject with peculiar authority and from the separate standpoints of the chemist and the engineer. Each recognizes the necessity of stopping the existing pollution and improving the harbor without loss of time and each critically discusses the extent and nature of the works which will be required. In each the conclusion is reached that a large part of the sewage which is tributary to the Lower East river and Harlem should be collected in intercepting sewers near the water front and carried by a tunnel to an island to be constructed in the sea at the mouth of the harbor, there to be discharged after enough of the impurities have been removed to insure that no nuisance or injury to health will result from the effluent. This project was described by the Metropolitan Sewerage Commission in its Preliminary Report VI, issued under date of February, 1913.*

The standard of cleanness proposed by the Commission in its report of August, 1912, was approved by Dr. Fowler and Mr. Watson as a guide of minimum requirements. Mr. Watson, like most of the other sanitary experts who have been called upon to advise in regard to this standard, would have the harbor waters kept cleaner than the Commission's provisions demand. Dr. Fowler discusses the present pollution in considerable detail and gives much attention to the need of cleanness with respect to these waters. Both experts lay emphasis upon the fact that the pollution has reached large proportions and is rapidly increasing.

The opinion is expressed by both experts that if the digestive capacity of the harbor for sewage is not to become overloaded to the point of an intense general nuisance, it will be necessary to carry a large part of the sewage away for disposal, it being, in their judgment, beyond the range of practicability to purify it sufficiently upon the shores of the territory in which it is produced to permit the effluent to be discharged into the neighboring waters.

It is pointed out that sewage works possessing high efficiency are so likely to produce odors and nuisance from flies that it is desirable to avoid the construction of such works within the city limits. For this reason it is their opinion that only such comparatively crude and simple processes as employ settling basins, grit chambers and screens should be considered for installation on the shores of Manhattan Island and central Brooklyn. There is no land anywhere within the limits of Greater New York upon which it would be permissible to construct works capable of purifying the sewage tributary to the Lower East river and Harlem by percolating filters, such as Mr. Watson employs at Birmingham, or contact beds, like those Dr. Fowler uses at Manchester, because of the nuisance which would result from the works.

After discussing the alternatives, Messrs. Fowler and Watson arrived at the conclusion that the proper solution of the problem was to carry the sewage naturally tributary to the Lower East river, and eventually that tributary to the Harlem, to an island to be built at sea. On this island the sewage should be passed through settling basins and perhaps treated with electrolyzed sea water, in accordance with a method with which the Metropolitan Sewerage Commission had made some experiments. The effluent from the island should be discharged in such a way as to cause it to be thoroughly mixed with large quantities of fresh sea water and the organic matters oxidized and rendered permanently harmless and inert by natural agencies.

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*See also Part II, Chap. VI, this report.

Neither Dr. Fowler nor Mr. Watson was dissuaded from endorsing this project on account of its cost. Their opinion was that the money for such sewage works as are necessary for the health, welfare and reputation of the port would be forthcoming, when once their necessity was understood. It is pointed out in the reports that other cities, and among them many small places, have spent much more per capita for sewage disposal than would be required here.

Mr. Watson's report gives considerable attention to the form of administration which is best suited for the construction and maintenance of the necessary sewers and disposal works and his experience gives him special qualifications to deal with this subject. He recommends that a commission be created which shall have charge of the building and maintenance of such sewage disposal stations as are necessary for New York and, in this suggestion, Dr. Fowler, with a knowledge of the details of the recommendation and familiar with the experience of cities and towns, concurs.

Following the critical reports of Messrs. Fowler and Watson, the Commission issued its Preliminary Report VI, in which the project of the ocean island was described, together with a considerable part of the argument which led the Commission to suggest this as a most desirable plan for the disposal of the Lower East river sewage. The reports of the two experts were published together as Preliminary Report VII in February, 1913.

Reports of Messrs. Fuller and Hering

In the summer of 1913, the Commission called upon Mr. George W. Fuller to state whether, in his judgment, the art of sewage treatment had reached such a point of development as to warrant New York City, at this time, in adopting a general plan and policy for main drainage and sewage disposal.

Mr. Fuller is a graduate of the Massachusetts Institute of Technology and was, for some years, bacteriologist in charge of the Lawrence Experiment Station of the Massachusetts State Board of Health, where extensive experiments in sewage and water purification have been carried on for years. He has been the sanitary adviser of many cities and towns in the United States in regard to water supplies and sewage disposal works. Mr. Fuller was one of the advisers of the Passaic Valley Sewerage Commissioners of New Jersey, which is constructing a trunk sewer to carry the sewage of Paterson, Newark and about twenty cities and towns in New Jersey with an estimated population in 1940 of 1,649,000 inhabitants to Upper New York bay for discharge.

In July, 1913, Mr. Rudolph Hering of New York was engaged by the Commission to review its work, the ground to be covered being the necessity and sufficiency of the plans which the Commission was preparing for the disposal of New York's sewage. It was stated that this study should consist of an examination of the Commission's reports and other data and a consideration of the engineering principles upon which the plans were prepared.

Mr. Hering, who is a prominent sanitary engineer, has long been recognized as a leading advocate of the disposal of sewage by discharge into natural bodies of water, where this can be done without harmful consequences. He has made numerous investigations and reports on the disposal of the sewage of cities. For some years Mr. Hering was the engineer of the Passaic Valley Sewerage Commissioners and took a prominent part in preparing their plan to discharge about 215,000,000 gallons of sewage per day into New York harbor. It was at first proposed to discharge this sewage in a crude condition, but later at the instance of the United States Government it was agreed that the sewage should first be passed through screens and settling basins.

The reports of Messrs. Fuller and Hering are similar in scope, treatment and conclusions. Each report proposes that the Commission's oxygen standard be cut in half and opposes the ocean island project for the protection of the Lower East river and in place of this plan recommends partial and local treatment for the sewage and its local discharge into the harbor.*

A large part of the reports of Messrs. Fuller and Hering is given to a discussion of the oxygen problem as it relates to the disposal of sewage through dilution with the harbor waters.

Mr. Fuller is of the opinion that the Commission's oxygen standard of a minimum of 3 c. c. per liter of water which, under summer conditions, is equivalent to about 58 per cent. of saturation can safely be reduced by one-half, provided that sludge is not allowed to accumulate to such an extent as to become a serious factor in absorbing oxygen from the water.

Mr. Hering recommends 25 per cent. as a minimum oxygen standard with frequent sludge removal. Both experts hold the opinion that sludge is an important factor, not only in exhausting oxygen from the water, but in producing nuisance from odors, a view which the Commission's investigations fully justify.

Elsewhere in this report (in the introductory note to the reports of the experts) will be found an expression of the Commission's opinion with respect to the oxygen standard.

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* As has been stated elsewhere, the reports of Messrs. Fuller and Hering have been supplemented by letters endorsing the Commission's recommendation that the city proceed with the gradual construction of the ocean island project.

Mr. Fuller states his opinion that the present status of the art of sewage disposal and the developments which are likely to be made in future warrant the adoption at this time of a definite policy for the main drainage of the city. Much space is given to a restatement of the Commission's position that the sewage of the whole city should not be collected to a single point for disposal. After reviewing the various forms in which this idea has been studied and the Commission's reasons for rejecting it,* Mr. Fuller concurs in the findings of the Commission on this proposition in all its phases.

Mr. Fuller confirms the opinion expressed by the Commission and by Messrs. Fowler, Watson and Datesman that highly efficient purification works, such as sprinkling filters, should not be located in the built-up parts of the city because of the danger that offensive odors will be produced by them. He concurs in the view of the Commission that the digestive capacity of the harbor for sewage should be utilized to as great an extent as is compatible with a due regard to the protection of the public health and the avoidance of nuisance. He agrees that the sludge and screenings extracted from the sewage can most advantageously be disposed of by barging to sea and he does not look forward to the probability that sewage can profitably be utilized in the near future. Two-story tanks of the Imhoff type, as compared with single-story tanks of the Dortmund type, are not justifiable, in his opinion, when the comparative cost of the two are taken into consideration.

In discussing processes of sewage treatment, Mr. Fuller lays much emphasis upon dilution and here, as elsewhere in his report, the discharge of sewage into natural bodies of water under proper conditions is strongly advocated as a reliable and efficient method of disposal. Aeration is described as a promising means of guarding against the putrefaction of sewage before treatment or discharge, but, except for limited quantities of unstable organic substances, aeration cannot be counted upon as an oxidizing agent. Electrolytic treatment to oxidize sewage seems to Mr. Fuller to have little value, but the electric production of a coagulant to precipitate colloidal and other non-settling organic matters, as done experimentally in the Commission's laboratory, may be of considerable use. Fine screens can remove more organic matter for a given cost than can any other type of apparatus and the limited and unsatisfactory experience which has been had with them in America should not prejudice one against their more reliable and continuous service as already shown in Germany, for example. The best results from sedimentation are to be had with detention periods of two hours. For New York, Mr. Fuller favors single-story tanks with hopper bottoms, such as the Commission has proposed throughout its planning, on the ground that it is undesirable to septicize the sludge near its points of origin. As compared with settling basins, screens are desirable only where it is necessary to remove relatively large sewage solids. Mr. Fuller does not approve of chemical precipitation unless in exceptional cases because of its cost and the difficulty of disposing of the resulting sludge.

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*See Preliminary Report I, issued September, 1911.

Mr. Fuller agrees with the Commission that the sewage of the Lower East river territory could be satisfactorily disposed of by diversion to an artificial island at sea, but he does not think it necessary to deal with it in this manner. Mr. Fuller is of the opinion that the Lower East river is capable of absorbing the sewage from the populations tributary to it for a great many years to come, providing the sewage is first screened or settled. He thinks that screens and sedimentation basins can be expected to be unobjectionable to public sentiment in the territory naturally tributary to the Lower East river and on the shores of the Hudson river. If, at some future time, it should prove desirable to divert some of the sewage from the Lower East river region to some point such as the outlet island, such partial diversion can then, in his opinion, be more economically affected than the removal of the sewage now.

The Commission's projects, with one exception, have received Mr. Hering's endorsement. He expresses himself as fully in accord with the view that the water of the Hudson will be capable of assimilating the sewage produced on the west side of Manhattan Island after the sewage is passed through grit chambers and screens and so discharged into the water as to insure prompt diffusion. He is heartily in accord with the proposition that the sewage be delivered as nearly as possible into the channel currents by means of submerged pipes having a number of openings discharging as nearly horizontal as practicable.

With regard to the Commission's projects for the Upper East River and Harlem Division, Mr. Hering has only favorable comment to make. He approves of the separation of the total area of the division into five subdivisions, so that the best conditions for collection and disposal can be secured. He considers that the proposed outfalls and disposal works are all well located. He says the Commission has quite properly recommended screening and detention of the floating matter at all the outfalls. He expresses the opinion that sufficient land should soon be secured in every case where plants will be required in future.

With reference to Jamaica bay, Mr. Hering agrees with the Commission that the location of Barren Island is well adapted for the final disposal of the sewage of the western part of Jamaica bay, including whatever treatment may be necessary. This point of discharge is, in his view, the best one now available, insuring, as it does, a sufficient dispersion and high dilution of the tank effluents. In Mr. Hering's opinion, at no time in the future will objectionable results appear from these works either in

Jamaica bay or along the beaches of Coney Island or Rockaway. If the outfall island is built for the relief of the Lower East river, Mr. Hering thinks that the western branch of the Jamaica bay intercepting sewer proposed by the Commission should be connected with the island instead of with works to be built at Barren Island.

The works proposed for Jo Cos Marsh are also approved. Mr. Hering mentions, without preference, the alternative plan of settling the sewage of the eastern part of Jamaica bay and subsequently discharging it into the ocean at a point about 4,000 feet from shore. In his opinion, no floating matter would drift toward the shore and no depositing matter would interfere with navigation or drift to the land.

Mr. Hering considers that the disposal of the sewage from Richmond offers few difficulties and he approves of the Commission's suggestions for separating the borough into subdivisions and collecting the sewage of each one separately for disposal at economical points after sufficient treatment has been given it to keep out of the water all floating matter and sludge. With the expectation that more thorough treatment may be necessary, Mr. Hering suggests that the works be so designed that they will permit additions to be made in case more complete treatment is found necessary in the future.

In regard to the final disposal of sludge, Mr. Hering is of opinion that where settling basins will be required, it will be cheaper to take the sludge out to sea than to dispose of it near-by, unless the sludge is of an inoffensive kind.

The project which the Commission recommended in its Preliminary Report VI for the construction of an outlet island for the relief of the Lower East river does not receive Mr. Hering's unqualified approval for the reason that he considers the cost of construction and operation larger and the degree of improvement higher than he thinks the circumstances require. As stated in his letter supplementing his report, he favors the gradual construction of the outlet island project, as the Commission has proposed.

Report of Mr. George E. Datesman

In the summer of 1913, the City of Philadelphia, which had been studying the problem of sewage disposal for some years, sent Mr. George E. Datesman, Principal Assistant Engineer of its Bureau of Surveys, to Europe to make a study of the main drainage and sewage disposal works of foreign cities. The scope of Mr. Datesman's inquiry included systems of collection, methods and materials of construction, comparison of screening and settling devices, ratios of dilution, conditions governing the adoption of a system of disposal, results obtained by different systems, economies and cost data. The countries visited were Germany, France, Belgium and England.

In view of the fact that the New York and Philadelphia conditions were somewhat alike, the Metropolitan Sewerage Commission obtained permission from Mr. Morris L. Cooke, Director of the Department of Public Works, and Mr. George S. Webster, Chief Engineer and Surveyor, of Philadelphia, for Mr. Datesman to come to New York and make a critical examination and report on the Commission's studies of the Lower East river problem from the standpoint of his Philadelphia and European investigations.

Mr. Datesman is a graduate of the Engineering Department of Lafayette College and a member of the American Society of Civil Engineers. He has been with the Bureau of Surveys, which is the central engineering department of Philadelphia, for twenty-six years, filling positions from Draftsman to Acting Chief Engineer. He has had charge, under the Chief Engineer, of sewer design, construction, port improvement, including dredging and pier construction, wharf and bulkhead work, and of city planning. Mr. Datesman has supervised the studies and plans for the collection, treatment and disposal of the sewage of Philadelphia from 1908 to the present date.

Various methods of treating the sewage locally before discharging it into the harbor waters are considered by Mr. Datesman in his report to the Metropolitan Sewerage Commission, with the result that settling basins, screens and grit chambers appear to him to afford the only means worthy of careful study. The large areas of land required and the certainty of nuisance lead him to exclude other and more efficient processes, such as percolating filters.

The practicability of constructing settling basins in various situations in the built-up sections of Manhattan and Brooklyn and on islands in the inner harbor is dealt with and the principal arguments in favor and in opposition to these projects are set forth by Mr. Datesman. It is his opinion that settling basins should not be built beneath the city streets nor on property acquired for the purpose in the built-up sections of the city, because of the large extent of such works, gases produced, cost as compared to their efficiency and the popular prejudice toward them which he feels sure would be aroused in their neighborhood.

The efficiency of settling basins and such screens as can be used in New York is regarded by Mr. Datesman as less than is commonly supposed, his point of view being concerned largely with the dissolved oxygen in the water and with deposits.

After considering the alternatives, Mr. Datesman expresses the opinion that the Commission's outlet island project affords the proper solution of the Lower East river problem. Like the Commission, he is willing to have his project carried out in progressive stages, feeling confident that time will show the necessity for the entire scheme.

Mr. Datesman agrees with Messrs. Watson and Fowler in thinking that some of the Wards Island sewage will have to be taken to the ocean outlet in course of time.

The experience of London, Paris, Berlin and other cities is cited to show that ample precedent exists for conveying sewage as far away as the Commission advises that the sewage of the Lower East river be taken.

Attention is called by Mr. Datesman to a marked difference between American and European practice in connecting the outlets of local sewerage systems to the interceptors used in main drainage works. Whereas American engineers run their interceptors beneath the local sewers and discharge the storm overflows through outlets which are virtually extensions of the local sewer outlets, in Europe the interceptors are run across the mouths of the local sewers to take in all the flow and discharge the storm excess from side outlets situated at conveniently located points. The European custom leads to larger interceptors with flatter grades and this results in a considerable saving in head and the avoidance of regulators possessing many moving parts. These are substantial advantages over what has heretofore been considered good practice in America, and the Commission has given careful attention to the design of interceptors in the manner which Mr. Datesman suggests.

III

THE COMMISSION'S OPINION WITH REGARD TO THE EXPERTS' REPORTS

While Messrs. Fowler, Watson and Datesman would have construction work started at once, in accordance with a comprehensive plan which would begin by giving a large measure of improvement to the waterways in the center of the city and, by additions and extensions, provide greater benefit in the course of a generation or more, as both the desire and need of improvement increase, Messrs. Fuller and Hering would be content with a scheme which would serve the immediate needs and postpone the construction of a complete system indefinitely. Nothing less than a removal to sea of all the Lower East river and Harlem river sewage will be sufficient in the distant future, according to Messrs. Fowler, Watson and Datesman, and they think the present is none too soon to provide for the works which will ultimately be necessary. Their idea is that the works should be built gradually so that it would be possible to stop the construction at any time when the needs of the situation were met.

Messrs. Fuller and Hering are confident that local and partial treatment will always be sufficient to fit the sewage for discharge into the city's waterways. The methods which Mr. Fuller considers suitable for local treatment are screens and settling basins. Where necessary, the final discharge would be through submerged outlets. Mr. Hering advocates "floatation chambers," screens, settling basins, coarse-grained filters (by which he means the more commonly called sprinkling filters) and submerged outlets. The probability of nuisance from sprinkling filters, if constructed in the built-up parts of New York, has been made so clear by Mr. Watson, whose experience with sprinklers exceeds that of any other engineer; the annoyance from the odors and flies which sprinkling filters produce are so well known to all who have seen them in operation in warm weather and the areas of land required for them are so large that the Commission and Messrs. Fowler, Fuller and Datesman have not felt warranted in including this form of treatment among the possibilities of local treatment. There therefore remain only screens and settling basins to be considered among the methods which may be used for the local and partial treatment of the sewage.

The Commission, which has given much study to the possible use of screens and settling basins under a wide variety of circumstances, is of the opinion that these types of apparatus can be of great help in disposing of the city's sewage. Each type of apparatus has its functions and limitations. Settling basins should not, in the Commission's opinion, be constructed in the built-up portions of the city. The plant proposed by the Commission for Wards Island, the four plants for the protection of the Upper East river and the plant on the ocean island would consist of settling basins. The Commission has recommended that that part of Manhattan's sewage which flows toward the Hudson, that part of Brooklyn's sewage which flows toward Upper New York bay and that part of the sewage of Manhattan and Brooklyn which is tributary to the Lower East river and which cannot be included in the ocean outlet should pass through screens.

In the Commission's opinion screens would be capable of removing most solid matters which are separately recognizable as of sewage origin, but would not effect much more improvement. The demand upon the dissolved oxygen would not be materially lessened. If settling basins were employed, about fifty per cent. of the solid matter would be removed and the demand which the organic matters of the sewage would make upon the dissolved oxygen would be reduced about twenty per cent.

No barrier would be provided by either screens or settling basins against the bacterial pollution of the water. With settling basins the sewage would be retained for a period of approximately two hours and the settlings in the form of black, semi-liquid sludge would be put on board vessels and transported to sea. Neither process would lessen the unpleasantly turbid appearance of the sewage streams at the points of discharge. This could only be prevented by discharging the sewage at the bottom of deep and rapidly flowing tidal channels.

As a general procedure it would not be feasible to construct settling basins beneath the streets. The space required would be prohibitive. If built upon the Emscher or Dortmund tank principle, either of which is more economical of space than any other known form, settling basins to provide two hours' settlement for 200,000,000 gallons of sewage would extend over one mile.

Settling tanks beneath the streets would be difficult to build and operate because of the confined space available, inconvenient shape of the tanks and tidal interference. Trouble in inspecting and cleaning the basins might be expected through want of proper light and ventilation. There would be considerable risk of nuisance and danger of explosion from the gases produced from the decomposition of the sewage, from gasolene fumes and from illuminating gas.

If the tanks were built elsewhere than under the streets, property would have to be acquired for them. The area of land required for settling basins to deal with 200,000,000 gallons per day would be about six acres.

The Commission does not share the opinion that the location of settling basins in the built-up parts of the city would be free from public objection. Granting that they would not produce offensive odors, it seems certain that property holders in the vicinity would make vigorous protest against the construction of such works, in the belief, mistaken though it might be, that the health and comfort of the neighborhood were seriously threatened. The object of the works would avowedly be to extract as much as possible of the offensive and dangerous materials from the sewage, and before they were disposed of they would have to be stored, transported to the water front, loaded upon vessels and shipped to sea.

As to cost, Mr. Fuller's preliminary estimates indicated to him that settling basins would be about one-fourth as expensive for 200,000,000 gallons of sewage as the Commission's outlet island project, including the purchase of the land which the settling basins would require. The costs assumed by Mr. Fuller for the outlet island scheme are based upon the Commission's earliest calculations for that project. Later studies have shown that the cost would be materially reduced by making less than the large allowance originally proposed for storm water. By providing for the collection of the dry-weather flow, the cost of the outlet island project can be reduced to about $14,000,000 and the annual charges to about $1,000,000.

A careful consideration of the cost of disposing of the same quantity of sewage by locally placed settling basins and submerged outfalls indicates an initial expense of $9,191,000 and an annual charge of $766,000. Comparison of the outlet island and local settling basin projects in accordance with the revised estimates indicates that the outlet island project would cost about one and one-half times more to build and about one and one-third times more to operate than would local and partial treatment by means of settling basins.

When the cost of the Commission's outlet island project is compared with the project for local settling basins on the basis of organic matter removed, a heavy balance is seen to lie in favor of the outlet island project. In this connection, it must be remembered that the outlet island would remove from the Lower East river 100 per cent. of the oxygen-demanding constituents of the sewage and that settling basins would remove not over 20 to 25 per cent. On the basis of each per cent. removed, the locally placed tanks would cost $22,589 and the outlet island $10,273. These calculations are based upon the assumption that about 200 million gallons per day would be dealt with in each case.

The ocean island could provide an outlet for the sewage of the western part of the Jamaica Bay Division and if so used would cost about $2,000,000 less than the project for local settling basins in the Lower East river territory and the project for collecting the sewage of the western Jamaica bay territory to Barren Island.

Another serious objection to the plan of locally placed settling tanks for the protection of the Lower East river lies in the fact that this method of disposing of the sewage would not lend itself to a more efficient treatment of the sewage in case sedimentation did not prove adequate. Unlike the sedimentation works recommended by the Commission for Wards Island and some other isolated points, settling tanks could not be converted into chemical precipitation basins in the compactly built-up sections of the city without involving serious chance of nuisance in the immediate neighborhood, much inconvenience in the handling of the chemicals and high cost for the disposal of the large volumes of sludge which would be produced. If, in the course of time, a more comprehensive plan had to be adopted to protect the Lower East river, as the Commission believes, it would be necessary to abandon the settling basins and carry out the Commission's plan of conveying the sewage to the outlet island. This procedure would then prove to be much more costly than if provided for in the first place.

To permit sludge to form on the river bottom of the Upper and Lower East rivers, and subsequently remove it by suction dredges would not, in the Commission's opinion, afford material help in solving the sewage problem. The sludge-making materials of sewage are capable of producing much harm both before they are deposited and during the time they are resting upon the harbor bottom, and the removal of this material by suction dredges would be attended by many practical difficulties, including interference with traffic, nuisance, expense, inconvenience and, when the dredges were at work, intense pollution of the overlying waters.

The engineering difficulties which have been pointed out in connection with the ocean island project have been foreseen by the Commission and the opinion is held that they can be overcome without serious trouble. The mean velocity calculated for the sewage in the force main from the pumping station to the island is 2½ feet per second and this would be obtained as soon as the works were built. It is to be noted that the ocean island project would not be built for the distant future, but would operate at its full capacity as soon as constructed.

The Commission has given careful attention to the possibility of carrying sewage from the Lower East river territory to an island to be built at the south of Governors Island, assuming, for the purposes of study, that permission could be obtained from the National Government for such construction. The cost of this island, including the construction of the works tributary to it and the tanks and appurtenances for treating the sewage, approaches the cost of the ocean island project, but the opportunities available for the disposal of the effluent would not be so satisfactory. It is to be remembered that the point at which the outfall would have to be located would be about 2½ miles from the Passaic Valley sewer, whose effluent may be expected to make a heavy and increasing demand upon the oxygen of the surrounding waters. Sprinkling filters at this point would not be permissible, in the Commission's opinion, because of the odors which they would produce, popular objection and cost.

Such weight as is to be given to established custom in engineering work is strongly opposed to the local and partial treatment of sewage as distinguished from its removal to a distant point for final disposition. The object of main drainage systems is to carry sewage away to some suitable point or points where as much of the offensive material as necessary can be removed, so that the effluent may be discharged into a neighboring lake, river or arm of the sea. Thus London carries its sewage beyond the limits of Greater London in order to find a suitable locality for settling basin treatment. Paris takes its sewage to Clichy and there pumps it to irrigation fields. Berlin pumps its sewage out of the city to farms situated in various directions. Boston and the cities and towns in its vicinity send their sewage to sea through three outlets situated as far as practicable from the harbor shores. These illustrations could be multiplied.

The employment of grit chambers and screens for the treatment of a large part of the sewage of New York represents to some extent a departure from established precedent. Examples are much more easily found of cities which screen their sewage within their limits than those which attempt more thorough treatment. Coarse screening and the removal of grit are not uncommonly done before sewage is sent to a distance and comparatively fine screening may be resorted to without serious probability of nuisance.

Mr. Fuller places reliance upon the experience of some other cities to support his position with regard to the ability of natural bodies of water to assimilate sewage, but he recognizes that the capacity of New York harbor with its oscillating salt water is not the same as the capacity of inland lakes, much less that of rivers, such as receive the sewage of Chicago, Columbus and Lawrence, for example. London is selected by him as affording an instructive instance of a city whose sewage is discharged into tidal water with but little preparatory treatment and with satisfactory results. The Metropolitan Sewerage Commission has taken pains to investigate the conditions at London among many other places where sewage is discharged into tidal water.

The following letter from the Secretary of the London Port Authority, dated December 10, 1913, describes a condition which, although tolerated in the Thames below London, would not be suitable in the built-up sections of New York City:

10th December, 1913.

Dear Sir:

In reply to your letter of the 2d inscant, your assumption is correct that notwithstanding the separation of the greater part of the solids from the London sewage effluent, there is enough solid matter remaining in suspension to represent in the course of the year a very large amount of mud-forming material which adds to the dredging obligations of the Authority.

In a report which I made on the subject in 1908 I found that the total volume of effluent passed into the River annually was ninety thousand millions of gallons which contained 12 to 13 grains per gallon of solid matter dried at boiling point. This, I roughly calculated, would represent about 330,000 cubic yards of mud.

With regard to unpleasant odors, they are most pronounced at the points of discharge, viz., Barking and Crossness, a distance of from 12 to 13 miles below London Bridge. On the flood tide an appreciable effect is noticed for a few miles above the London Bridge, and on the ebb tide this would be perceptible until the wider and salter waters of the River were reached; say, down to Northfleet Hope, a distance of about 25 miles below London Bridge, or 12 miles below the point of discharge. The odors, however, would not extend inland beyond the immediate banks of the River.

I regret that I am unable to tell you precisely how often the temperature rises above 65 degrees or higher, as the English summers greatly vary in temperature. With the average amount of sunshine I should say that this temperature is reached toward the end of June and, after a week of dry, sunny weather, would always be attained up to and including the first week in September.

Yours faithfully,

(Signed) F. AGLIFFE,
Secretary.

The President,
Metropolitan Sewerage Commission of New York,
17 Battery Place, N. Y. City.

The experience of London, Hamburg, Washington and Philadelphia are cited by Mr. Hering to show that sewage is often discharged untreated, or nearly so, into water courses of brackish and upland water without nuisance. It may be remarked that these references do not support the argument for a partial and local treatment of the sewage, inasmuch as they refer to situations quite unlike that of New York. The foregoing letter from the Port of London Authority shows that the Thames for a dozen miles above and below the outlets produces odors which would be inadmissible in New York. Nor should Hamburg be taken as a model, since the discharge of that city's sewage into the turbid Elbe is visible from the shore. Mr. Hering cites Washington, but it should be explained that the Washington sewage is probably one of the most dilute in the United States and the Potomac river is an alluvial stream whose abundant storm waters soon flush away such sewage impurities as gain access to it. Philadelphia is referred to, but it is significant that Philadelphia is completing plans for a system of main drainage and sewage disposal which is likely to be far more radical than that proposed by the Metropolitan Sewerage Commission for New York.

SECTION I

REPORT OF GILBERT J. FOWLER, D. Sc.

To the President and Members of the Metropolitan Sewerage Commission of New York.

Gentlemen: In accordance with the request of the Metropolitan Sewerage Commission, conveyed to me by the President, Dr. George A. Soper, in a letter dated September 27, 1912, I arrived in New York on the 10th November, 1912, and remained, with brief absences in Boston, till Wednesday, the 27th November.

During this time the following inspections were made:

By water: 1. Upper bay,
2. East river to Long Island sound,
3. Round Manhattan Island,
4. Through the Narrows to Far Rockaway and into Jamaica bay.
By land: 5. To Gravesend bay, Coney Island, Sheepshead bay and Canarsie, visiting disposal works at Sheepshead bay, Paerdegat basin and 26th Ward;
6. To Newtown creek, returning to Manhattan, recrossing the Lower East river below Hell Gate and skirting the edge of the Upper East river, including Steinway, Flushing bay, Whitestone and Douglaston.

I also visited Boston, and through the courtesy of the Massachusetts Board of Health, was able to inspect the three types of sea outfall there. The same day I visited the Lawrence experimental station and discussed the work being done with the chief chemist. On these various expeditions numerous photos were taken of important points such as some of the larger sewer outlets, proposed places of discharge, etc.

A good deal of time was spent in the laboratory of the Commission, overlooking and discussing experiments on the possibilities of electrolyzed sea water as a precipitating and sterilizing agent for the sewage. I also had much conversation and discussion with reference to the data accumulated by the Commission and was shown numerous data hitherto unpublished, especially in reference to the possibilities of complete nitrification taking place in mixtures of sea water and fresh water.

The President was good enough to demonstrate for me the method used by the Commission in their fundamentally important work on the dissolved oxygen in New York harbor. The method is rapid and accurate and well suited to the conditions of investigation. I have carefully studied both before and since my visit to New York the extensive and valuable reports issued by the Commission as well as the report by Major Black and Prof. Phelps.

Immediate Conclusions

I was impressed at the outset by the vastness and complexity of the problem to be dealt with. London may have a larger present population, but the conditions for discharge are infinitely simpler.

In addition to the rapidly increasing population directly or indirectly discharging its sewage into the harbor, the problem is complicated by the outstanding facts, viz.:—(1) the growing scarcity and value of unbuilt upon land in the vicinity of the harbor,

(2) the comparatively small amount of water available for flushing out the bay, this being limited practically to the flow of the Hudson. The thickly populated districts abutting on the Harlem river and the Lower East river discharge into waters which ebb and flow with the tide, but suffer very little actual change, little or no excess water passing out of the bay or into it at each tide.

As a consequence, the conditions to be met with in the Harlem and Lower East rivers call for immediate action. Not only is the bottom polluted, but the water, even in favorably situated portions of these rivers, is deficient in oxygen, in the majority of cases to nearly 50 per cent. In many places there are local nuisances already, and floating fæcal matter, paper, etc., are in frequent evidence. What the conditions are likely to be when the surrounding districts, increasing as they are now doing, to say the population of 1940, it is not pleasant to conjecture. It is evident that something will have to be done here and done at once. When the volume of sewage to be dealt with—over 350 million gallons per day at the present time and more than 700 million gallons by 1940—is considered, it is evident that for this section of the work alone considerable expenditure will have to be faced.*

In view of the very large expenditure involved, it is difficult to exaggerate the importance of adequate preliminary studies and the work of the Commission throughout appears to me to be a model of the way in which such investigations should be carried out. The conditions are so complicated, owing to the diversified character of the land and water areas constituting New York harbor and its surroundings, that endeavors to reproduce them artificially, as is often done in research work, are likely to be only partially successful. The method of thoroughly studying the actual state of things obtaining in the bay and other waters in the vicinity under all conditions of season, tide and weather, as has been done by the Commission, seems the only possible one, and the work has been done with masterly completeness. No question necessary for the formation of a right judgment on the questions which should be settled at this time appears to have been left unstudied by the Commission.

The citizens of New York may rest assured that the large sum of money they will be called upon to pay for the protection of their harbor will not be asked for except as the result of opinions formed after years of study much more complete than is generally given to such a subject. Every year, however, the conditions now existing must necessarily grow worse and, while in the case of a growing science like that of sewage disposal it is well to hasten slowly, yet through the labors of the Commission there will exist no justification on the score of imperfectly known data for postponing certain most necessary works.

PRINCIPLES GOVERNING CONSIDERATION OF THE PROBLEM

The conditions which must be realized if the constituents of sewage are to be rendered inoffensive or finally mineralized are essentially the same whether the disposal be by irrigation upon land, filtration through artificial biological filters, or dilution with fresh or salt water. The process is in all cases one of oxidation, *i. e.*, practically speaking, combustion, and if it is to be conducted without nuisance, enough oxygen must be present at all stages of the process to prevent the formation of evil-smelling products.

It is perfectly legitimate to use the oxygen dissolved either in sea or river water in order to oxidize sewage. Under proper conditions of discharge, complete transformation and mineralization of the sewage matters can be effected in this way with less nuisance than often accompanies treatment on filters or on land.

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*Report Metropolitan Sewerage Commission of New York, August, 1912, p. 28.

The question of the margin of safety which should be allowed if nuisance is to be avoided has been the subject of reports by a number of well-known experts to the Metropolitan Sewage Commission* and all of these reports agreed that under no circumstances should be dissolved oxygen in the harbor be allowed to sink to below 50 per cent. of saturation. In this opinion I concur. It will, however, be most unwise to be content with a margin simply sufficient to barely eliminate nuisance.

Two main considerations govern the situation from the point of view of public policy; these may be described as considerations of *Health* and *Welfare.*

Health. There are obvious ways in which public health may be directly affected by the filthy conditions of parts of the harbor or even by the apparently innocuous discharge of sewage effluent.

It is not a pleasant sight to see numbers of floating fæces washing in and about piers where food supplies are landed from lighters, some of which have a low free board. Gulls and flies may also quite possibly be carriers of infectious material under such conditions.

The question of oysters is of more direct importance. Even if sewage or sewage effluent is actually sterilized, the growth of oysters near an outfall is always a possible source of danger, and while it is quite easy to exaggerate this, yet it can never be in accordance with right sanitation for an article of food to be thus contaminated.

The pollution of bathing sites has been dealt with at length by the Commission.† The conditions which at present exist are unsatisfactory in the extreme.

The carrying of polluted driftwood daily into the homes of the poor in the neighborhood of the water front does not tend to raise the standard of cleanliness in such homes and should be prevented rather by stopping pollution than by forbidding what is in itself a reasonable and thrifty proceeding.

But even more important than the direct and obvious ways in which the public health is affected by the polluted condition of the harbor waters is the practically unconscious lowering of that sense of decency and cleanliness of living which must be maintained if the efforts of social reformers are to have any serious result.

Crowds of people from the poorer quarters of New York throng the recreation piers and pleasure drives on the water front. If it is obvious to them that those in authority, who have the power, are yet unconcerned to abate uncleanly surroundings, the already not inconsiderable effort required to maintain a decent spot of home life in a mean environment will be rendered even harder to achieve.

Welfare. The second consideration, viz., that of *welfare,* as it has been termed, is perhaps less obvious, but is most important when expensive works, the use of which is partly for future generations, have to be considered.

A study of the history of sanitation, such, for example, as was possible in the historical section at the International Hygiene Exhibition in Dresden in 1911, will show that, up to comparatively recent times, conditions were tolerated which to us would seem unspeakable. Yet even now the standard of requirement is constantly rising. One may, indeed, frankly say that the modern American bathroom, both in its fittings and the frequency with which it is to be found, is a distinct advance upon what is common even in England. Such a bathroom, however, increases the difficulty of the sewage problem, and in looking forward to the future, similar advances in public requirements must always be reckoned with. The idealism manifested in such great buildings as the Pennsylvania Railroad station and the Metropolitan Museum of Art and the parks and playgrounds of the city will find its further development in a demand for brightness and beauty in the surrounding water spaces. Nor is such idealism unrelated to more purely economic prosperity. The true solution of any problem is true at all points, sanitary, aesthetic, ethical and economic.

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*Report Metropolitan Sewerage Commission of New York, August, 1912, pp. 69-164.

†Report Metropolitan Sewerage Commission of New York, April 30, 1910, pp. 486-497.

Apart from the question of affecting the vitality, and consequently wage earning capacity of the people, the reputation of a port is a very essential factor in its commercial prosperity. The condition of the Clyde and of the Manchester ship canal was for many years a by-word. The great sewerage and sewage disposal works at Glasgow, carried out at a total cost of over £2,000,000 for 800,000 people, have been the means of rehabilitating the reputation of the Clyde and adding to the amenities of life, pleasure trips being now possible from the Broomielaw to the Firth of Clyde.

The large amount of money spent on sewage works in the watershed of the Mersey and Irwell is, apart from the increasing expenditure of Manchester itself, slowly but steadily improving the water of the Manchester ship canal.

At one time the stench from the polluted Thames in hot weather rendered the committee rooms in the houses of parliament in London uninhabitable. By the removal of the sewage to treatment works and outfalls lower down the river this nuisance has been abolished, and London is now one of the healthiest and best drained cities in the world.

In the case of the three cities above referred to, their works were carried out under urgent pressure of obvious and almost intolerable nuisances from the polluted streams. New York should deal with her problem before such acute conditions arise.

The foregoing general view of the situation clearly indicates that any scheme which is decided upon must not block the commercial avenues of the future. It must be so designed as to be capable of expansion as the needs of the city increase.

Possible Methods of Dealing with Sewage. The various possible methods which are available for dealing with sewage on the large scale may be broadly divided into:

1. Direct discharge into water,
2. Discharge after screening,
3. Discharge after sedimentation,
4. Discharge after chemical treatment,
5. Discharge after filtration in some form,
6. Discharge after combination of processes.

The proportional amount of impurities removed by these processes depends on numerous factors, *e. g.*, the freshness and strength of the sewage. Thus, screening will remove a much greater proportional amount from very fresh sewage than from sewage which has been mixed and churned up for many miles in a trunk sewer. Chemical treatment is more economical with strong sewage than with weak, and therefore is of less advantage with American sewage than with European.

Very roughly, it may perhaps be assumed that under the conditions existing in New York, of the nuisance-producing solid material in sewage capable of producing deposits of sludge, the following percentages can be removed by the respective processes:

Screening and grit chambers	3-6 per cent.
Short sedimentation	50 "
Chemical treatment	75 "

None of these processes seriously affects matters in solution. Filtration affects not only the finely divided colloidal matter still present after the foregoing processes, but also oxidizes substances in solution.

Which of these methods can be used at any of the various proposed points of outfall in New York harbor is to be determined by local conditions. What these conditions are is considered in the next section.

The Present Polluted Condition of the Harbor

Broadly, the waters of that part of New York harbor which lies in New York State may be considered separately as follows:

The Hudson river,
The Upper bay,
The East river and the Harlem river,
Jamaica bay.

Of these the Hudson river contains the most dissolved oxygen, this amounting to over 90 per cent. of saturation in the centre of the river in the northern part of Manhattan and diminishing to 60 per cent. near the Battery. The Hudson river supplies practically the only water available for flushing the harbor. All along the edge of the Hudson among the piers objectionable conditions exist.

The Upper Bay. All the pollutions from the waters entering the harbor at certain states of the tide, as well as those resulting from direct sewer discharges are mixed by tidal currents in the Upper bay and a proportion of the solid matters is doubtless deposited there during the ebb and flow of the tide. This is evidenced by the polluted character of the dredgings from the bottom of the Upper bay at nearly every point of observation. Considerable deposit of sludge has been found south of Governor's Island.

The general appearance of the waters of the Upper bay is by no means attractive. Large fields of sleek, or oily film, are frequent and, more objectionable, are masses of floating débris in which large quantities of fæcal matter are often entangled. The Gowanus canal is little better than an open sewer, there being an insufficient circulation of water to dilute the large volumes of sewage discharged into it.

The East River and the Harlem River. It is on these rivers, especially in the Lower East river and the Harlem, that, as already stated, conditions exist which call for urgent remedy.

Large sewers discharge from the thickly populated districts on both sides of these waterways and there is little or no net tidal discharge. As a result, the bottom of the upper East river as far as Throg's Neck at the entrance to Long Island Sound is foul, and in the Lower East river, in places unaffected by the ebb and flow of the tidal currents, foul deposits occur.

In the Lower East river from the Williamsburg Bridge to Hell Gate the dissolved oxygen present, especially in the summer months, is not much more than 50 per cent. of saturation.* In some parts of the Harlem river it is less than this. There are portions of the Harlem river already approaching the condition of the Manchester ship canal, while Newtown creek has practically reached that condition. In the vicinity of

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*In the summer of 1912 some samples of water from the Lower East river, near the Brooklyn Bridge, were found to contain 43 per cent. of oxygen.

Wallabout basin there is a large sewer outlet which produces a small lake of sewage in its vicinity, which is most objectionable.

There is no doubt that if the sewage which now enters crude into the Lower East river and the Harlem river could be taken up and dealt with in a satisfactory manner very great benefit would accrue not only to these waterways, but also to the Upper bay and Upper East river, into which much of the sewage eventually finds its way.

Jamaica Bay. The characteristic feature of Jamaica bay and its vicinity is the growing summer population of numerous pleasure resorts, such as Bergen Beach, Arverne, Edgemere, Canarsie and Rockaway. The conditions which I saw in November were, therefore, hardly typical. Effluents from treatment works at Sheepshead bay and the 26th Ward, though obviously imperfectly purified, were not the cause of serious visible pollution.

In view of the increasing population and of the schemes of harbor development which are being considered, it will be necessary before very long comprehensively to deal with the sewage which at present discharges into the bay.

The question of oyster pollution must here also be dealt with, and it should be clearly understood that ordinary methods of treating sewage give little protection from a bacteriological point of view, while processes of sterilization may easily produce a false sense of security. It would seem best for oysters not to be taken near densely populated centres, as under such circumstances the chance of pollution, apart from the sewage which is discharged from actual sewage outfalls, are considerable.

Proposed Remedies

Sewage Tributary to the Lower East River and Harlem River. As already emphasized, the first point of attack in dealing with the problem of purification of New York harbor is the Lower East river and the Harlem river, and I have given my most careful consideration to this part of the Commission's work.

After much study the Commission have concluded, and I think rightly, that the only point where large quantities of sewage can be treated in this neighborhood is at Wards Island. It is possible to pick up the sewage which at present discharges into the Harlem river and also that which is turned out of the large sewer at Hunt's Point and bring it all to Ward's Island, where it can be treated in settling tanks and the heavier sludge removed.

Some 124 million gallons daily would be thus dealt with at once, and over 400 million by 1940,* and would be discharged into the swift tidal currents at Hell Gate, where the best possible conditions exist for mixing.

Sedimentation, however, leaves a large proportion of potential solids still present, as well as all the impurities in solution. Treatment by chemicals instead of by plain sedimentation would remove a further proportion of the suspended impurities, but the treatment in this way of such large volumes of sewage as may be taken there involves numerous difficulties and greatly increased cost, which would weigh heavily against the advantages obtained. Further purification, by filtration, at Wards Island is impracticable, and also not to be recommended so near large centres of population, owing to the possibilities of aerial nuisance and fly trouble on large areas of filters.

It becomes matter, therefore, for careful consideration how far the concentration of the sewage to one point and discharge into the local waters after elimination of the grosser solids would really relieve the situation. It is to this point that most careful thought has been given and the bearing of all the available data studied under every aspect.

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*Preliminary Report IV, of the Metropolitan Sewerage Commission on the Disposal of New York's Sewage, July, 1912.

Owing to the fact that the waters rushing through Hell Gate only pass back and forth with the tide and do not really get away to the ocean, it is evident that whatever sewage is discharged at Hell Gate is largely dependent for its oxidation on the oxygen in the water with which it mixes in one tide. The Lower East river is, however, highly polluted and the discharged effluent will therefore not get much help from it. The situation, in fact, is only improved by the elimination of the grosser solids from the sewage of the Harlem district. If the situation is to be radically improved the conclusion seems inevitable that some sewage must be removed from the Lower East river.

From figures supplied me by the Commission, I calculate that if the sewage of the Harlem territory is collected and passed through settlement tanks on Wards Island, and if the sewage of those parts of Brooklyn and Queens which would ordinarily discharge into the Lower East river be removed altogether, there will then be a dilution representing 1 of raw sewage to 200 of water in the Lower East river at mean low tide.

This is a considerable improvement on present conditions, representing a removal from the Harlem and Upper and Lower East rivers together, of about 50 per cent. of the total sewage which at present pollutes them.

It is, however, from the Manhattan waterfront that the greatest proportional volume of sewage enters the Lower East river. It exceeds the volume discharged into this division of the harbor from Brooklyn and Queens by about 50 per cent. The further conclusion, therefore, is forced upon one that a really satisfactory solution of the problem must involve the removal of this sewage also. Indeed, a study of the statistics show that if this is not done the Lower East river in 1940 will revert to a condition even worse than exists to-day.

Disposal at Sea of that Part of the Sewage of Brooklyn, Queens and Manhattan Which Would Ordinarily Discharge into the Lower East River. The conditions discussed in the foregoing section show clearly that the sewage from these districts will have to be removed from the Lower East river if the situation is to be properly dealt with.

From the researches of the Commission there would appear to be three possible outlets for this sewage.

The first possibility is to take it to Barren Island and there treat it in tanks, followed, possibly, by some form of filtration and discharge it near the entrance to Jamaica bay. At the same point would be collected the sewage now very imperfectly dealt with at the various sewage works discharging into the creeks on the northern shore of Jamaica bay. The point of outlet would be at the entrance to Jamaica bay.

Barren Island itself is, however, little more than half a mile from the large summer population on the Rockaway peninsula, and if, as is not at all improbable in hot summer weather, some amount of smell should arise from the filters, it is not far enough away to prevent a nuisance to these people. Moreover, the point at which the effluent would discharge is not half a mile from thronged bathing beaches. There are, therefore, these grave objections to an outlet near Barren Island.

A second alternative proposition has been considered, viz., the removal of the sewage to the west side of Staten Island, with the erection of purification works there. Apart from engineering difficulties which I am informed exist in carrying so much sewage across the very deep channel of the Narrows, the conditions of final discharge would render purification by biological filters necessary, and similar objections would again arise in regard to nuisance from these as have been pointed out in regard to the Barren Island project.

Under these circumstances a third alternative has been suggested which seems to me to have much to recommend it. This proposition is to build an artificial island well out in the Atlantic, nearly three miles from the shore of Coney Island, and there construct settling tanks, and discharge the effluent after settlement of the bulk of the suspended solids, into deep water, with proper engineering precautions to ensure thorough mixing of the effluent with the sea water.

After inspection of the Boston sea outfalls I am clearly of the opinion that no point of outlet should be less than 40 feet in depth, and that the discharge should be continuous so as to minimize the quantity sent out in any interval of time.

The sludge deposited in the tanks could be readily taken well out to sea in tank steamers of the pattern used in Europe, as at Glasgow, Manchester, Salford and London.

I understand that the island can be made without difficulty from the spoil and débris from excavations in New York City at present taken out to sea, or from sand pumped from the bottom of the sea. I understand also that it will be possible to increase the number and length of the outfall pipes as more and more sewage is coupled up to the island, so that the effluent will always be well distributed in the sea water. The operations can be carried on without causing nuisance to anyone and the conditions for sea disposal of sludge in tank steamers are very simple. The scheme is capable of indefinite expansion as more sewage is taken up, as the size of the island itself can be increased as extensions to the works are required.

Many matters rather of detail remain for further consideration in regard to the methods of treatment employed both at what may be termed "Atlantic" Island and Wards Island. The design of the settlement tanks to be employed is a question of importance. A form of tank is to be preferred which would expose as little water surface as possible and also allow automatic removal of the sludge by the pressure of the supernatant water. A modified form of two-story tank would seem well suited to this purpose.

The sludge produced by the thorough fermentation which takes place in the so-called Emscher tanks, while greatly reduced in bulk and offensiveness, would offer some difficulties in carrying to sea, owing to its being saturated with gas. It is possible that judicious admixture with salt water would obviate this difficulty. In any event the disposal of sludge is the least difficult part of the problem. There will not be more, for a long time at any rate, than is at present handled at the London outfalls, and the conditions of sea disposal are simpler in the case of New York.

For reasons indicated when referring to works on Wards Island, I do not recommend treatment by chemical precipitants. I think, however, that very careful study deserves to be given to the practicability of adding a small dose of chlorine to the effluent, *e. g.*, by the addition of a certain volume of electrolyzed sea water. This would serve the double purpose of deodorizing what may be a somewhat malodorous effluent after its long travel through the sewers, and a further important advantage would lie in preventing an immediate call upon the dissolved oxygen in the sea at the point of discharge, and thus giving time for more thorough mixing and aeration to take place.

Some Further Problems. There are many matters of importance subsidiary to the large scheme outlined above which call for brief mention.

A system of screens and catchpits has been designed for Manhattan Island, which could afterwards be used for screening storm water, overflowing from the main sewers later to be built. It is in my view important that this should be carried out, in order that even after large sums have been spent on main sewers and outfall works there should not be public disappointment when visible pollution is seen to be present after every shower of rain. Before such refuse is removed, however, means must be at hand for its rapid incineration in suitably placed destructors.

The scheme of outfalls and outfall works designed by the Commission for the districts abutting on the Upper East river seems to me to be adequate, at any rate, for many years. The outlets are all in deep water and the conditions resemble those of the Clyde summer resorts or English lakes, where the sewage of a fairly large population is disposed of without serious difficulty.

Time did not permit me to study the problems connected with Staten Island actually on the spot. From a perusal of the Commission's report on the disposal of the sewage of the Richmond Division there would not appear to be any special difficulty in dealing with the situation as far as regards the responsibility of New York City.

In the Arthur Kill and Kill van Kull we are approaching the problems of New Jersey. I have not been called upon to express an opinion on matters which are a subject of litigation. One may, however, safely say that a resolute handling by New York City of her own problems is likely to facilitate an equitable conclusion.

Summary and Conclusions

After careful consideration of the situation as it has been placed before me, I am of opinion that the sewage of the Harlem district should be collected and treated in sedimentation tanks on Ward's Island.

This will relieve the immediate and pressing situation on the Harlem river. It will, however, do little or nothing to improve the Lower East river.

It is of equal importance, therefore, that the scheme be pressed forward of driving a main sewer southwards through Brooklyn to an artificial island well out from shore in the Atlantic ocean, where tanks could be built for settling out the heavier suspended matters and removing them to sea.

Into this main sewer would first be discharged that part of the sewage of Brooklyn and Manhattan which at present passes in a crude state into the Lower East river. Later more of the sewage of Manhattan should be coupled up to this sewer, the outlets at the artificial island being extended with each large increment of sewage.

Next, the sewage from the Jamaica Bay Division might be brought to the island, and finally, if thought desirable, the sewage which during all this time had received treatment at Wards Island.

By this sequence of procedure the experience gained at Wards Island would be of value in designing the final disposal at the "Atlantic Island," and at any rate a large proportion of the money expended in tanks, etc., at Wards Island will have been redeemed before the works are abandoned. The expenditure in sewers in the Harlem district will be for permanent works alone.

The order of carrying out the various needful works and the time over which the construction should extend would all be matters within the control of the permanent commission suggested by my colleague, Mr. Watson, with whose views on this aspect of the question I heartily concur.

This same central board or commission would care for the other less immediately pressing, but still highly important, problems referred to in the later paragraphs of the foregoing report.

The above represents in broad outline the lines upon which, in my opinion, the City of New York should proceed in its endeavor to obtain a harbor worthy of itself.

It must again be emphasized that no time should be lost in setting about the actual carrying out of the scheme. It must of necessity take a number of years to complete, and equally of necessity the condition of the harbor waters must become progressively worse if nothing is done, and will indeed probably be worse before the first instalment of the work is completed.

I am, however, confident that the citizens of New York will show the same determination and largeness of outlook already manifested in their great water supply projects, their colossal railway undertakings and magnificent bridges and public institutions, in this further effort after social well-being, and will build the works necessary to cleanse the harbor and make it worthy in every respect of its great position as the Gateway of the West.

Respectfully submitted,

MANCHESTER, February 10, 1913. GILBERT J. FOWLER.

SECTION II

REPORT OF JOHN D. WATSON, C. E.

TO THE PRESIDENT AND MEMBERS OF THE METROPOLITAN SEWERAGE COMMISSION OF NEW YORK.

GENTLEMEN: I have given the problem of the sewerage and the sewage disposal of your great city my close and careful consideration during the past two months.

The fortnight which I spent in the city in the end of November and beginning of December gave point and animation to the study which was not otherwise possible, and I take this opportunity of thanking you for the ready access you gave me to all your documents, plans and analytical figures, and for the facilities with which you provided me in the inspection of every part of the area which I thought it essential to visit. Allow me also to record my appreciation of the exhaustive preliminary investigations which you have made. These far exceed anything which I have hitherto had experience of, and the fact of your having printed them renders unnecessary reference to details which otherwise would have had to be given in this report.

THE POLLUTED CONDITION OF THE HARBOR

If there were any prospect of limits being set to the bounds of New York, if there were any signs that sufficient accommodation had already been made for the shipping of the port, or if the waters of the harbor were so foul that the citizens had ceased to regard them as valuable for oher than utilitarian purposes, the disposal of the sewage—vast as the volume of that is—would be comparatively easy. But it is quite otherwise. The city is more than the capital of a country; it is the greatest city of a continent. The harbor is the gateway to the United States, and the noble rivers which find a ready outlet into it form, with the harbor proper, a port which affords at all stages of the tide no halting welcome to vessels of the greatest burden.

When I first had the pleasure of seeing the Hudson between Albany and New York I was greatly impressed by its grandeur and its purity; when I motored along its left bank from Riverside Park toward the city boundary at Yonkers in brilliant sunshine I thought it the Queen of Rivers, and I cannot believe that the average citizen would willingly allow it to become visibly polluted with sewage, yet the facts to which I shall refer will prove that it is necessary to take steps now to guard against such a contingency in the immediate future.

Visible Pollution. The numerous analyses of the harbor waters made by your own officers, supported by men of such eminence as Professor Phelps, Dr. Adeney and Dr. Fowler, and the clear evidence of pollution which I have witnessed, lead me to the opinion that continuance of the present unhampered license to pollute can only lead to disaster. When it can be shown that even now the condition of the harbor in summer is obviously unclean, it is only a question of time when an ever-increasing population discharging an incremental amount of sewage and trade waste into what must be practically a stationary volume of harbor water will convert into a nuisance what should be one of the brightest and best of the city's possession.

One of my first actions in prosecuting this study was to investigate the condition of the harbor water, and even in the end of November I found at several places a slight smell of sewage. In ferrying across the river between 92d Street and Astoria I observed innumerable particles of paper and even pieces of excrementitious matter in the water. Sea gulls indicated where the public sewers debouched directly into the river.

In many places in the East, the Harlem and the Hudson rivers, the Gowanus and Wallabout bays, visible evidence of the presence of sewage was only too apparent. Near the Battery I saw food which had just been unloaded from a boat that was moored in what looked more like sewage than clean water. At another place (Gowanus canal) I witnessed the ebullition of gas, apparently arising from septicized sewage sludge. Large flows of greasy sleek and débris were to be seen at frequent intervals. Open ends of sewers spewing their filthy contents into the rivers are of much too frequent occurrence.

One and all demonstrate the same lesson—that the time has arrived when a standard of cleanness should be set and maintained. If such conditions were offensive in November and December, it is obvious that they must be worse in the hot seasons of the year. Of course, offensiveness to sight and smell do not necessarily constitute a nuisance which is dangerous to health, but as no self-respecting community would tolerate streets that were rarely scavenged because no injury to health could be traced to them, no port of the first rank should permit excrement paper, straw and grease to flow to and fro on the surface of the chief highway into the city because it could not be proved that a human being had died as the result.

The Proper Standard of Cleanness. The standard of cleanness which you suggest, and which I heartily approve, should be reasonably but strictly enforced.* Liquid pollution, though less obtrusive, is not less in need of prevention, and it is in the interest of the community to see that any recognized standard which may be decided upon should be conscientiously adhered to. What the standard should be is a question which you have already submitted to a number of well-known experts, and they have all united in saying that the dissolved oxygen in the harbor water should not be allowed to fall below 50 per cent. or 60 per cent. of the saturation limit. Colonel Black and Professor Phelps suggested that it should not be allowed to fall below 70 per cent. saturation, and this figure is more in accordance with my own view; indeed, I go further and say that an even higher standard is feasible if the project recommended later in this report is approved and given effect to.

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*Report Metropolitan Sewerage Commission of New York, August, 1912, page 70.

1. Garbage, offal or solid matter recognizable as of sewage origin shall not be visible in any of the harbor waters.
2. Marked discoloration or turbidity, due to sewage or trade wastes, effervescence, oily sleek, odor or deposits, shall not occur except perhaps in the immediate vicinity of sewer outfalls, and then only to such an extent and in such places as may be permitted by the authority having jurisdiction over the sanitary condition of the harbor.
3. The discharge of sewage shall not materially contribute to the formation of deposits injurious to navigation.
4. Except in the immediate vicinity of docks and piers and sewer outfalls, the dissolved oxygen in the water shall not fall below 3.0 cubic centimeters per litre of water.† Near docks and piers there should always be sufficient oxygen in the water to prevent nuisance from odors.
5. The quality of the water at points suitable for bathing and oyster culture should conform substantially as to bacterial purity to a drinking water standard. It is not practicable to maintain so high a standard in any part of the harbor north of the Narrows or in the Arthur Kill. In the Lower bay and elsewhere, bathing and the taking of shellfish cannot be considered free from danger of disease within a mile of a sewer outfall.

†With 60 per cent. of sea water and 40 per cent. of land water and at the extreme summer temperature of 80 degrees F., 3.0 cubic centimeters of oxygen per litre corresponds to 58 per cent. of saturation.

The result of 289 samples tested by you for dissolved oxygen in the summer of 1911 show clearly the polluted state of some parts of the harbor. Taking 100 per cent. as the saturation point, or the normal condition of clean water, the following comparison of average figures speaks volumes:

Lower New York bay	98	per cent.
Long Island Sound near Throgs Neck	96	"
Hudson river, a few miles above Manhattan Island	81	"
Narrows	73	"
Upper East river	71	"
Kill van Kull	66	"
Hudson river to north of Manhattan Island	64	"
Upper New York bay	63	"
Lower East river	55	"
Newark bay	54	"
Harlem river	42	"

Average figures in such a study do not quite suffice, for as the strength of a chain is the weakest link, so the lowest figures obtained (30 per cent. at the lower end of the Harlem in July, 1911) indicate the danger conditions which sanitarians would strain every nerve to avert.*

The Increasing Discharge of Sewage. When one remembers that the population of New York was only 2,500,000 in 1890, and that in 1905 it was 4,000,000, a careful estimate of its probable growth in the future is essential to arrive at a wise judgment in the matter of sewage disposal.

Estimates have been made by several authorities, including Freeman, who said the
population in 1940 would be 7,652,000
and Laidlaw, who said it would be 8,662,829
The New York Telephone Company's estimate is 8,747,000
and the Board of Water Supply's estimate is 9,258,600

The average of these suggest a probable population of the city in 1940 of 8,580,107, a figure which proximates to your own estimate of 9,000,000, which, be it remembered, is based on the Census figure of 1910, and on this account is more likely to be accurate.

The prospective population which should be reckoned, however, is not 9,000,000, but 12,000,000, the population of the metropolitan area. The question as to what extent the harbor is likely to be burdened with impurities in 1940, assuming that nothing is done in the interval, depends on population more than anything else, and whether that population is located north, south, east or west of the harbor makes no difference. Artificial boundaries, therefore (state or other), are obviously not so important to the issue as *watershed,* and far fetched as it may appear to be at first sight, the manner of disposing of the sewage of the City of Albany and every other populous place built and to be built on the banks of the Hudson will materially affect the problem under consideration. This will be apparent if it is conceded that the recuperative influence of the harbor depends very largely upon the purity or otherwise of the Hudson as it enters New York City.

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*The percentage of oxygen fell still lower in 1912. The average for the year: Hudson river off Pier A, 55 per cent.; Narrows, 70 per cent.; Kill van Kull, 65 per cent.; Upper New York bay, 64 per cent.; Lower East River, 47 per cent.

The act of assimilation can be carried on only in the presence of oxygen, and it is therefore essential to conserve that oxygen as much as possible.

The table which I have quoted to show the relative state of purity at various specified places as measured by percentage of loss of oxygen is eloquent condemnation of the existing system, a condemnation which is only partially mitigated by the naturally and wonderfully even admixture of the harbor water as shown by the voluminous observations you have made.

In studying this question the fact that the volume of sewage must increase constantly has to be set in juxtaposition with the fact that the clean water from whence the oxygen is derived must remain very much the same in all time. Nor should the floating population as represented by the trade of the harbor be ignored. This is certainly a difficult problem, and I fear it will be impossible to exclude sewage from this source altogether; it is the more important, therefore, that the authorities deal effectively with the sewage from the stationary population which is under control.

Cleanness, a Commercial Necessity. On the day I arrived in New York the newspapers referred to a remarkable speech by the Mayor on the subject of the growth of imports and exports at several harbors of the United States. The occasion for this speech was the 144th anniversary of the organization of the Chamber of Commerce, and it was shown that the increase of trade at New York was far and away greater than at any other port in the country.

Since 1898 the increase at the port of New York was......... 111 per cent.
" " " " " " " " Philadelphia was...... 75 "
" " " " " " " " Boston was............ 17 "
" " " decrease " " " " Baltimore was......... 7 "

All the facts and considerations of the case lead me to the conclusion that the community must bestir itself if it would retain for its harbor the good name which is now associated with it. Let the cases of Marseilles and Glasgow be a warning. Many years ago the Clyde became so foul that even poor trippers declined to board pleasure steamers nearer to the Broomielaw than Greenock, several miles down the river. Since that time large sums of money have been spent on sewage disposal works, but the bad reputation justly associated with the name of the Glasgow harbor years ago will not be got rid of for many years to come. Every port has a duty to every other port, which if faithfully observed would inaugurate a state of things that would go far to lessen the duties of port, sanitary and quarantine officers.

Discussion of the Metropolitan Sewerage Commission's Four Schemes for the Purification of the Harbor

What then is the most practicable, the most hygienic and the most permanently economical scheme to adopt? I have studied the various schemes put forward in the admirable reports which you have sent to the Mayor of the City since September, 1911.*

Although the schemes enumerated in your reports may not have exhausted every phase of what you term the art of sewage purification, yet in my view you have considered every method applicable to New York which can be regarded as reasonably practicable.

> *Scheme 1* refers to the application of sewage to land. (Broad irrigation and intermittent filtration.)
>
> *Scheme 2* refers to filtration of sewage through biological filters (bacteria beds.
>
> *Scheme 3* refers to treatment of sewage by a variety of methods at various points of outfall, each case being adapted to its special circumstances, and the ultimate disposal of partially purified liquid into the nearest water course.
>
> *Scheme 4* refers to the conveyance of a large part of the sewage out to the Atlantic ocean with the minimum of treatment.

Scheme 1

Application of the Sewage to Land

The popularity of irrigation as a means of purifying sewage is on the wane, chiefly owing to the extensive area required and the unsuitability of the land available.

The Berlin farm, which is the largest in Europe, continues to do good work. The largest farm in England was at Birmingham, but some years ago when land could no longer be obtained for less than three times its agricultural value, the authorities abandoned irrigation in favor of the intensive method of purification on bacteria beds. The largest farm in France is at Paris, and there also the authorities contemplate a change of method whenever it is necessary to increase the purification plant.

Where all the conditions are favorable, irrigation is undoubtedly successful as a vehicle of purification, and one which generally yields consistently good effluents, but in New York the farm would be so colossal in extent that the conditions would not be invariably favorable. The available land is, I fear, limited to Long Island, the area required would exceed 150 square miles. It would necessarily vary in its adaptability for the purpose, and although the standard of purification need not be exceptionally high in view of the large volume of water into which it would ultimately be discharged, it would still be necessary to limit the volume of sewage to 10,000 or 12,000 gallons per acre, unless a great expenditure for underdrainage were undertaken.

Sanitary Objections. A great area of land lying between Amityville and Quogue overlies one of the sources of the city's present water supply, and its use for sewage purification would be a potential source of plague which no one would care to risk.

The mere saturation of 150 square miles of land with sewage would be a menace to the inhabitants obliged to reside in the district and would be sure to produce mal-odors during certain states of the atmosphere, which would be highly objectionable, even if they did not markedly influence the health statistics of the district.

I disapprove of this method of purifying New York sewage on grounds quite apart from cost; nevertheless, it is important to note that it is the most costly of the schemes brought forward, and would probably amount to $180,000,000; this, too, assumes that land could be acquired for about $500 per acre—a somewhat sanguine estimate.

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*Metropolitan Sewerage Commission's Preliminary Reports on the Disposal of New York's Sewage, I to V inclusive.

SCHEME 2

OXIDATION IN BACTERIA BEDS

The epoch-making experiments of the Massachusetts State Board of Health have led to the adoption of what has been called the intensive method of purification. By this biological filters are made to take the place of land, and in your case would probably purify 140 times as much sewage as the same area of land under irrigation. It is a method which is almost invariably adopted in modern works which are located some distance from sea, lake or river.

To carry the whole or the major portion of the New York sewage to Barren Island and then treat it on bacterial filters would be costly, and could only be justified if it could be shown that a specially good affluent is essential at the point of discharge.

As the oyster beds will probably depreciate in value as the population of the district increases, it would not be wise on this account alone to incur the expense of this operation, more particularly as it is now admitted on all hands that the passage of sewage through a biological filter does not necessarily deprive it of pathogenic organisms, and in order to protect the oysters from the attack of a stray typhoid bacillus it would in this case be necessary to sterilize before 1940 a quantity of sewage equal to about 700,000,000 gallons.

Danger of Nuisance. Perhaps Barren Island is the very best site available for placing an installation of percolating filters, but it would appear as if Jamaica bay were on the eve of great developments, and that Barren Island would not for long be the isolated place it now is. I regard it as of the utmost importance to establish sewage purification works where they are not likely to become a nuisance, and I have grave doubts about the wisdom of placing so vast an area as 1,000 acres of bacteria beds so near to an industrial center as they would be on Barren Island. In contemplating such a scheme there is a factor which should be taken into account, and that is the after effects of the evaporation of so much foul liquid as there must necessarily be from such an area of filters.

In 1911, when the summer weather in England was warmer than usual, there were complaints of smell nuisance at Henley, where the sewage is of about the same strength as the average American sewage, and where it is distributed over rectangular percolating beds by mechanical distributors moving backwards and forwards. Complaints were also made by residents near the Birmingham works, where the sewage is sprayed over the beds by fixed nozzles.

The chief lesson to be learned from the 1911 experience is that an increase of flies is to be looked for in the neighborhood of bacteria beds in hot weather, and that objectional smell adjacent to them is more pronounced during prolonged hot weather than at other times, *e. g.*, seasons like the average English summer, when the temperature rarely exceeds 65° Fahr. in the shade. But a much more serious drawback to a great area of bacteria beds during spells of *prolonged hot weather* is the formation of vaporous "clouds," due to the evaporation of sewage. These clouds appear to form over the beds in quiet weather. They rise to some distance above the earth, and at sundown, when the earth begins to cool, they return not alone as refreshing dew, but with offensive odor. If this occurred only in the vicinity of the bacteria beds, where the land is generally less valuable than at some distance, it would not be so serious in its consequences, but it generally occurs at some distance from the bacteria beds, the direction and distance depending upon the tendency and the velocity of the wind.

Cost. Of course, it is only the mal-odorous element in sewage that makes this phenomenon noticeable; evaporation from clean water would act precisely in a similar manner, but it would manifest itself in welcome dew on the grass. This led me to adopt at Birmingham the use of hypochlorite of calcium with excellent results, but the cost would be a serious matter where 700,000,000 gallons had to be treated each day; indeed, the bare probability of hypochlorite of either calcum or sodium (and the latter is even more effective) having to be used frequently, would be sufficient in itself to retard the adoption of a scheme which would be many times as large as anything now in existence. It is obvious that climate is of paramount importance.

The initial cost of 1,000 acres of biological filters to deal with 700,000,000 gallons of sewage would be not less than $140,000,000, apart from maintenance charges. Altogether, I agree that the Commission would not be justified in espousing this scheme as the best available for New York.

Scheme 3

Local Treatment Works and Outfalls

It is probably not far from the truth to say that the only purification of organic matter known to nature is an oxidizing one, which is brought about indirectly by the agency of bacteria, but whether the vehicle by which the process is brought to fruition is the irrigation farm, the biological filter or dilution with large volumes of clean water, the "combustion" process is practically the same.

To protect the harbor from pollution it is neither essential to confine the purifying process to one method nor to one locality, but whether it is expedient or wise to construct dozens of sewage purification plants in and around New York is an entirely different matter. Sewage from the various districts delineated on the plans could be sufficiently treated to admit of being discharged in the adjacent waters without creating a nuisance, but in some cases the treatment would have to be very circumscribed, and a greater burden would be placed upon the assimilating powers of the waters than they ought to be called upon to bear.

Essential Details. It is unnecessary for me to refer in detail to the various outfalls that would be required under this scheme. Suffice it to say that I have examined many of the suggested sites, with the invariable result that they all appear to me to have been chosen with great judgment and engineering skill. It is more than probable, however, that if Scheme 3 finds most favor, the sites shown on the plans, and referred to in your reports, may have to be altered when negotiations for the purchase of those sites are begun; this will be found to be specially true in the case in the nineteen outfalls on Manhattan Island.

Under this scheme it would be necessary to lay sewers towards an outfall which would terminate in the deepest water available in the vicinity, where it would be dispersed by a complete system of moderate sized outlets so placed as to enter the stream transversely to the flow and in sufficient number to encourage equal diffusion. Each outfall should be protected by grit chambers and settling basins in duplicate; the former should be provided with every appliance requisite to remove solids of large size, road grit, rags, etc.

Disposal of the Sludge. The basins should be built so as to induce the sludge arrested by mechanical or chemical precipitation (as may be found best under circumstances which vary considerably at different outfalls) to collect at, say, the apex of an inverted cone or pyramid, and the sludge collected should be pumped daily into steamboats built for the purpose and removed well out to sea. This system of getting rid of sludge is well suited to a scheme which would have all its sludge tanks within easy reach of navigable water.

In my view the sludge should be removed daily so as to obviate smell nuisance. The only alternative would be to septicize the sludge in Emscher tanks, but this would mean large and deep tanks, which would be incompatible with the conditions obtaining at some of the outfalls, particularly those in Manhattan, where the sludge tanks would perforce be placed in the streets abutting on the bulkhead and shore lines. The experience of the engineers at London, Glasgow and Manchester puts at rest any doubt as to the practicability of removing unsepticized sludge by steamboat, but there is nothing equally convincing to show that if it were in a state of active fermentation it could be so easily removed and so quickly lost to view when dropped into the ocean.

Only Limited Treatment Practicable at Wards Island. If such a scheme as this were to be carried out, its weakness would probably become apparent first at Wards Island, where 302,000,000 gallons of sewage will have to be treated daily in 1940. The reasons I have given against the establishment of a great area of filter beds at Barren Island are even more potent when applied to Wards Island, so that either mechanical or chemical precipitation would in the present state of knowledge have to be resorted to, and neither process is efficient enough to warrant me in suggesting that such a volume of effluent could be discharged into the East river without unduly drawing upon the oxygen of the harbor water.

One of the leading factors in considering the Wards Island problem is the fact that the river, so called, is without a continuous flow of fresh water towards the sea; any sewage effluent, therefore, would have to rely upon admixture with the water of a tide in order to obtain the necessary supply of oxygen to obviate putrefaction, and considering the volume available for this purpose, I am doubtful whether the results would be acceptable at all seasons of the year. Of course, the sedimentation process, including screening and sludge removal to sea, or that process plus the addition of a coagulant to help mechanical precipitation, do not exhaust the great sources of power in nature, and it is quite possible that we may before many years are over realize the practicability of electrolyzed sea water. Your laboratory experiments stimulate me with hope, but I cannot in the present state of my knowledge recommend them as a practical solution of the problem.

Under this scheme there would be many outlets, all of which would require to be equipped with screens, grit chambers, tanks, and some kind of treatment works, before the effluent could be discharged and left for the nearest water to complete its purification by assimilation.

SCHEME 4

CONVEYANCE OF A LARGE PART OF THE SEWAGE TO SEA

The distinctive feature of this scheme is the provision of subterranean channels, or great sewers, into which each part of the municipality embraced within a prescribed area would have the indisputable right to discharge sewage and trades wastes without let or hindrance, knowing that the sewage would be conveyed right out to the Atlantic ocean. Nothing in the nature of treatment beyond arresting solids that would otherwise obstruct the pumps would be undertaken *en route*.

One important feature of this scheme would be the formation of an island in the sea about three miles south of Coney Island. The formation of such an island is by no means unprecedented, but the idea of forming one some miles from land for the sole purpose of treating sewage is a novelty in the history of sewage purification.

Scheme 4 involves pumping the sewage, screening it, arresting a proportion of the suspended solids in sedimentation tanks to be constructed on the island, and thereafter leading it by a series of pipes into deep water to secure effectual diffusion.

Having the sewage tanks on the island would obviate the usual troublesome claims for compensation in respect of depreciation of value of adjacent property. The island could be extended almost indefinitely as occasion for extension arose. Its position would be the best possible from which the superintendent of the works might observe the ebb and flow of the tide, and regulate the emptying of the sedimentation tanks.

The Treatment Necessary. The question of the extent to which sedimentation should be carried is one which will gradually settle itself. I do not think it will be necessary to effect settlement until after the first section of the work has been in operation for some time, but as section after section is completed it will be found necessary to arrest the solids in tanks, made with the view of concentrating the sludge at the bottom of either conical or pyramidal pockets placed at an elevation to induce the sludge to flow by gravitation.

The precise site of the proposed island will require careful consideration, but that shown on your plan appears to be feasible. Excepting rip-rap for the external formation, nearly all the material for making it can be readily and cheaply obtained, chiefly from (1) débris or spoil from building sites which at present is dumped into the ocean; (2) spoil from the tunnels and terminating shaft, and (3) sand pumped from the adjacent sand banks.

The Progressive Steps in this Scheme. The first step to be taken if this scheme is entertained is to collect sewage from those parts of Manhattan and Brooklyn which border on the East river, convey it by tunnel to a central pumping station at Wallabout, near the Navy Yard, and lift it to another pumping station at Sheepshead bay, whence it would be conveyed to the projected island for disposal.

The population of the districts to be served at first by this instalment, and the dry weather flow of sewage pertaining thereto, are as follows:

District	Population, 1915	Sewage, Gallons per Day
Manhattan	680,000	99,000,000
Brooklyn	732,000	104,000,000
Total,	1,412,000	203,000,000

The Wallabout pumping station would lift 133,000,000 gallons coming from the north 18 feet in height, and 70,000,000 gallons from the south 33 feet in height, and the Sheepshead bay station 203,000,000 gallons about 38 feet in height.

This instalment could be executed for about $18,000,000, which would entail for interest (at 4½% for 50 years), together with maintenance charges, an annual payment of $1,500,000, but I do not recommend you to limit the size of the tunnel to a carrying capacity of 400,000,000 gallons, or about twice the dry weather flow, as I believe the second instalment of the scheme should be undertaken soon after the completion of the first.

The second instalment, I apprehend, would be to couple up the intercepting sewer which would serve the Jamaica Bay Division, shown on the plan accompanying your report to the Mayor, dated November, 1911.

The third instalment of the work should bring the sewage of the Upper East river and Harlem Division into the system, and the fourth would take in Richmond and as much of New Jersey as may be determined.

In my opinion all the intercepting sewers should be capable of conveying not less than twice the dry weather flow before storm water is shed into the nearest watercourse; this would correspond favorably with the English practice of conveying six times the dry weather flow,* or rather less than 200 gallons per head per day.

NEED OF A PERMANENT SEWAGE DISPOSAL COMMISSION

Of the four projects thus briefly outlined as possible schemes for adoption, I have a decided preference for Scheme 4. I admit that Scheme 3 is feasible, but it lacks finality and possesses features which should be avoided when possible, *e. g.*, the numerous outfalls and the drawbacks attaching to them in the eyes of the general public, their not invariably suitable locations, and their inevitable increase in number as the population increases. What influences me most in favor of Scheme 4 is the conviction that where it is possible to remove the bulk of the sewage of New York entirely away from its source to the ocean *it should be so removed,* although the cost may be somewhat higher than it would be under a project like Scheme 3.

In a great city where such public services as water supply, sewerage and sewage disposal are indispensable, and where several self-governing municipalities benefit by the common service, it is essential in the interests of good and economical administration that there should be a permanent commission, with jurisdiction over the whole area. Such a general commission from its very constitution is enabled to deal with questions more comprehensively than local boards, commissions, departments or bureaus can do. Probably an example of what I mean may be found by reference to the endeavor to improve the insanitary conditions of the Gowanus canal, where a local sewer bureau tried to remedy a nuisance by conveying a stagnant, putrid liquid from one locality to another in the same neighborhood. No doubt the bureau did the only thing available to them at the time, but they were obviously restricted in their outlook, and were forced by circumstances to mitigate rather than remedy the evil, whereas if it had been possible for them to order the polluted waters of the canal to be conveyed beyond the municipal boundaries to the ocean the evil would have been effectively remedied. A municipal engineer's work is often unfairly criticized because the effects of being hemmed in by surrounding boroughs is not adequately appreciated. Administrative questions, like sewerage, are not invariably united, but here they should be under one commission or board, and it is with the object of devising a workable scheme for keeping the harbor free from solid as well as liquid impurities that I suggest the formation of a commission to be entrusted with the duty of making and keeping pure (or reasonably pure) the national waters.

Proper Functions of a Permanent Commission. The constitution of such a commission would have to be carefully framed by those who are well versed in existing statutes and interstate law, but I venture to suggest one or two points which should be carefully embodied in the constitution.

The whole responsibility for maintaining clean waters within the prescribed area should rest upon the commission, and they should have all necessary power to enforce their regulations.

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*For comparison between English and American sewage, See Preliminary Report VI, of the Metropolitan Sewerage Commission of New York, January, 1913.

The commission should be responsible for the design of all intercepting sewers, pumping stations, tanks, outfalls, etc., essential for the construction of a complete installation of sewerage and sewage disposal works. The board should also be made responsible for the construction of these works and for their subsequent maintenance.

Each borough or municipality must have the same right to connect to an intercepting sewer or sewers that they now have to discharge sewage into harbor, river or watercourse.

The commission should be charged with the duty of seeing that pollution, which must be inevitable until the intercepting sewers or subterranean tunnels are all built and connected to the ocean outfall, does not increase, even although it should be necessary to construct temporary works for the purpose.

The joint board or commission should have ample power to decide whether an intercepting sewer or any other work is required, and to allocate the cost of construction to the users. It should also have power to regulate by by-laws, or otherwise, everything which pertains to the keeping clean of the harbors, rivers, canals or watercourses within the area for which it is responsible. If it is usual to give such commissions rating, borrowing or financial powers, the board should be so empowered.

In recommending the adoption of Scheme 4 it is not to be assumed that I advocate its complete execution at once. If I have succeeded in presenting the whole project correctly, it will be apparent to all that the dominating factor is and must continue to be the condition of what I have called the national waters. As it stands at present, the putrefactive liquid entering them increases daily; their power of oxidizing foul liquid is practically stationary, and as every sewer is diverted to the Atlantic ocean by being coupled up to the system under Scheme 4, their condition will improve. I do, however, advocate progressive, consistent advancement until the completion of the scheme be attained, which I hope will be not later than 1925.

Necessity for Immediate Action

I cannot say too distinctly that there is need for immediate action. The nature and extent of the tunnel work bars haste and precludes all chance of redeeming lost opportunities; therefore no opportunities should be lost.

Generally, I am in sympathy with the plans you have prepared; particularly do I espouse what you call Project 1 as the first step to be taken. There should, however, be a comprehensive plan matured if possible in conjunction with the engineers of the several sewer bureau, which will indicate how every link of the complete scheme will be caught up in regular progressive stages. This is the more important as there might be more or less prolonged intervals between each successive stage.

It will probably cost not less than $100,000,000 to complete Scheme 4, undoubtedly the largest sum ever contemplated for such a purpose, but no scheme has hitherto been designed for the service of 12,000,000 people. Many small towns have spent more *per capita* than this estimate implies, and frequently all they gained was the removal of a liquid which possessed potential elements of plague. The citizens by approving the conveyance of all the sewage to the Atlantic will gain that and more, for they will at once purify their harbor and rivers, which never will cease to be the most priceless and most striking physical characteristic of New York.

Comparison with European Undertakings. If one were to attempt a comparison between the cost of the sewerage systems of European capitals and what is now proposed for New York, the great disparity between the quantities of potable water used by the inhabitants of cities of the Eastern and Western Hemispheres would arrest attention. The world has been startled by the magnitude of your water schemes. Any European city would have regarded 114 gallons *per capita* as an extravagant allowance, yet this—which is equal to a daily supply of 500,000,000 gallons—is what is now obtained from the Croton works alone, but rather than curtail that supply, or do anything which might be interpreted to favor a limited use of water for public health purposes, the authorities determined to carry out a gigantic scheme to obtain another 500,000,000 gallons of water per day, this time from the Catskill mountains. The magnitude of the undertaking and the aggregate cost of bringing in 1,000,000,000 gallons per day will place the New York water supply in a category by itself when a history of the world's great water works comes to be written.

The consumption of water has a direct relationship to a city's sewerage system as regards cost, and it is incumbent upon an engineer in recommending a scheme to satisfy himself that it is not only sound as an engineering proposition, but that it is financially possible. The facts I have brought to your recollection go a long way to show that a scheme of sewage disposal which will ultimately cost $100,000,000 and involve an annual outlay of $5,000,000 for the benefit of 12,000,000 people is not disproportionate to the requirements of the city. But I have not relied alone upon the example of the water works in coming to this decision. The numerous public schools, seats of learning, public institutions, colossal buildings, wide streets, stupendous bridges of unparalleled width, not to speak of railroad, canal and private enterprise, the most recent examples of which may be found in the Pennsylvania and Grand Central stations, which between them have cost not less than $300,000,000, all direct one's attention to indisputable evidence of prosperity and progress, and to what is of even more importance, the attitude of mind which shows that the people have a profound faith in the future greatness of their marvellous city.

It is quite unnecessary to caution you that all estimates of cost, so far as they have been prepared by me, must be regarded as of a tentative character, and should be accepted cautiously until complete surveys, detailed plans and sections are made, and schedules of quantities drawn up—nevertheless they seem to me to be quite ample for the work contemplated.

I am, gentlemen, your obedient servant,

John D. Watson.

Birmingham, 31st January, 1913.

SECTION III

REPORT OF GEORGE W. FULLER, C. E.*

To the President and Members of the Metropolitan Sewerage Commission,
17 Battery Place, New York, N. Y.

Gentlemen: Pursuant to your request of July 29, 1913, I beg to report herewith my views on the present status of the art of sewage disposal and on the probable future development of processes of sewage treatment with special reference to New York City; and particularly my opinion as to whether the art of sewage treatment has been developed to such a point as to warrant the adoption at this time of a definite policy and plan for the main drainage of this city, with the necessary works for the disposal of sewage.

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* See also Appendix to Mr. Fuller's Report, pages 213-218, and Correspondence with Mr. Fuller, page 218.

Brief Summary of General Conclusions

In my judgment the art of sewage treatment has reached a point such as to warrant at this time the adoption of a definite policy and general plan for the main drainage works of New York City.

There is between the early advisers of the Commission and myself a serious difference of opinion as to the extent to which the oxygen dissolved in the harbor waters may properly be lessened by the digestion therein of clarified sewage matters.

There is also some uncertainty as to the extent to which the harbor waters will show improvement from the systematic prevention of sludge deposits accumulating on the harbor bottom, particularly around slips and in the vicinity of sewer outlets. In part this uncertainty is owing to difficulties in interpreting the relation between the deoxygenating effects as measured by laboratory methods and as actually encountered under local conditions in practice.

But there is no room for doubt as to the correctness of the conclusion that the best method of disposing of New York sewage is by mixing it promptly with sufficient water in the neighboring watercourses, after substantial removal of solid sewage matters, which now either float on the surface or subside.

In particular I agree with the Commission:

1. That visible evidences of sewage in the harbor waters should be removed by first subjecting the sewage to fine screening or sedimentation.

2. That the subdivision of the city into natural drainage districts for separate treatment is proper.

3. That the discharge of sewage should be through submerged outfalls into deep water so as to affect a prompt and thorough mixing wherever such submerged outfalls can be built without serious objection and present conditions of pollution demand improvement.

4. That all construction should be made to conform to the general plan adopted by a central authority.

Harbor waters will digest, other things being equal, more settled sewage than raw sewage. And in my opinion the treatment of the New York sewage as required by fine screens or sedimentation will allow the harbor waters to digest the sewage of a population materially greater than indicated by the published opinion of the Commission.

Some portions of the harbor waters, such as Gowanus canal, Wallabout bay, Newtown creek, Harlem river and the waters in the immediate vicinity of some of the larger sewer outlets and over some of the Manhattan and Brooklyn shore line require relief at once from objectionable conditions of sewage pollution.

Other portions of the harbor waters, such as the Lower Hudson river, Lower bay, etc., have a sufficient volume of water for dilution for many years to come, and the problem is not a complicated one, provided the sewage is clarified by devices now available and is suitably distributed so as to avoid shore pollution.

Uncertainty as to procedure relates to the intermediate set of conditions where the available water is neither obviously insufficient on the one hand, nor obviously ample on the other. The Lower East river is one of these bodies of water.

As to the "outlet island" project for the sewage of the Lower East river division, as tentatively recommended early in 1913 by the Commission, I am of the opinion that the evidence now available does not warrant the conclusion that this project is the proper one.

My views as to residual oxygen and the significance of solid sewage matters lead me to the opinion that local plants for clarifying the sewage now entering the Lower East river are entitled to much fuller consideration than I have noted in the reports which you have published up to this time. It is my belief that local clarification devices can be installed along the water front of the Lower East river so as to accomplish all necessary relief from the present uncleanly conditions. I believe that the solution of the problem of this particular division depends essentially on the matter of cost and that the program should provide for that method which will give sufficient improvement to the local waters at least burden to the taxpayers when account is taken both of the investment and operating costs.

Basis of Study

In order to make this report concise and responsive to the New York problem, it is necessary briefly to refer to the more characteristic features resulting from the methods now practiced in the disposal of the sewage of New York City, the needs as to corrective treatment and the methods proposed for that purpose.

I have noted the contents of the several comprehensive reports issued by the Commission and I have also inspected personally the principal watercourses into which the sewage of Greater New York now discharges.

Influence of New York Sewage on the Waters of the Harbor and Vicinity

I find that the conditions attending the present discharge of the New York City sewage into the adjoining tidal waters may be briefly summarized as follows:

1. Visible suspended matter unquestionably of sewage origin is to be noted at various places in the watercourses into which the city sewage is discharged. Among the most conspicuous places for noting fecal matters is the Lower East river.

2. Relatively large pieces of garbage, refuse, driftwood and other sizable débris are to be noted at various places. Only a small part of these originate in the sewage.

3. An oily film or greasy coating, sometimes spoken of as "sleek," is visible in some places. It is doubtful whether such appearances exist to a seriously objectionable extent over other than quite limited areas of the New York waters.

4. Deposits of solid sewage matters have occurred over quite substantial portions of Upper New York bay, the Harlem river, in the East and Hudson rivers, in and around slips where sewage is discharged from the outer end of neighboring piers.

5. These deposits of sewage sludge are undergoing decomposition at a more or less rapid rate. In deep water they do not produce offensive conditions, although they are undoubtedly robbing the overlying water of some of its dissolved oxygen. In the vicinity of some of the slips, however, the deposits are subjected to objectionable putrefaction during the warmer months. Such putrefactive decomposition, with its attendant gasification, occurs in various degrees of intensity and at certain places becomes objectionable in its offensiveness. Such conditions I have noted in the vicinity of Gowanus canal, Wallabout channel, Newtown creek and the Harlem river.

6. Bathing in these waters in the vicinity of the outlets of the New York sewers is an unsanitary practice unless the sewage-polluted waters are thoroughly and systematically purified before use in the bathing establishments.

7. In the waters north of the Narrows and at some places south thereof, as well as in many locations in Jamaica bay, the waters are in all probability unsafe for use in the shell-fish industry.

8. Eliminating questions of shell-fish, bathing and perhaps some other means of

personal contact with the water, there is no reason to believe that the discharge of sewage of New York City into the adjoining waters has a measurable effect upon the public health.

9. Analytical data indicate that there has recently been, according to the analyses made by the Commission, quite a marked reduction in the atmospheric oxygen dissolved in the waters receiving New York City sewage. Representative data for the years 1909, 1911 and 1913 may be summarized in tabular form, as follows:

TABLE XIX

Divisions of Harbor.	Percentage Saturation of Oxygen.		
	1909	1911	1913
Harlem river	55	42	29
Lower Hudson river	72	62	57
Upper East river	86	69	48
Lower East river	65	54	43
Upper bay	67	72	66
Kill van Kull	79	70	65
Narrows	83	76	69

NOTE.—While not attempting to explain the striking reduction in oxygen content given by these figures, it is to be noted that increase of population is not an adequate explanation for this reduction.

10. As regards major fish life, there are undoubtedly polluted zones where the dissolved oxygen content and other features resulting from the discharge of sewage are such as to make unsuitable the waters in the vicinity for supporting fish life. It is not believed, however, that this is generally true of the main watercourses.

11. The local sewage problem consists essentially in the corrective treatment of nuisances offensive to the senses of sight and smell and in the consideration of measures to be adopted sooner or later in the development of a program which shall result in maintaining a reasonable degree of cleanness in the waters receiving the sewage of New York City.

PROPOSED STANDARDS OF CLEANNESS

I have noted the proposed degree of cleanness which the Commission recommends for the waters in the vicinity of New York City, as follows:

> "1. Garbage, offal or solid matter recognizable as of sewage origin shall not be visible in any of the harbor waters.
>
> "2. Marked discolorization or turbidity, due to sewage or trade wastes, effervescence, oily sleek, odor or deposits, shall not occur except perhaps in the immediate vicinity of sewer outfalls, and then only to such an extent and in such places as may be permitted by the authority having jurisdiction over the sanitary condition of the harbor.
>
> "3. The discharge of sewage shall not materially contribute to the formation of deposits injurious to navigation.
>
> "4. Except in the immediate vicinity of docks, piers and sewer outfalls, the dissolved oxygen in the water shall not fall below 3 cubic centimeters per liter of water. With 60 per cent. of sea water and 40 per cent. of land water and at the extreme summer temperature of 80 degrees Fahrenheit, 3 cubic centimeters of oxygen per liter corresponds to 58 per cent. of saturation. Near docks and

> piers there should always be sufficient oxygen in the water to prevent nuisance from odors.
>
> "5. The quality of the water at points suitable for bathing and oyster culture should conform substantially as to bacterial purity to a drinking water standard. It is not practicable to maintain so high a standard in any part of the harbor north of the Narrows, or in the Arthur Kill. In the Lower bay and elsewhere bathing and the taking of shell-fish cannot be considered free from danger of disease within a mile of a sewer outfall."

As a set of rules, the observance of which should be the aim in considering the disposal of sewage for New York City, I do not believe that serious exception can be taken to the foregoing standards, reasonably interpreted, other than to Rule 4 specifying the minimum residual quantity of dissolved oxygen considered permissible in the waters except at docks, piers and sewer outfalls.

In my judgment this minimum quantity of 3 cubic centimeters of dissolved oxygen per liter, equal to 4.3 parts per million, and about 58 per cent. of saturation at summer temperatures for the harbor water, consisting of about 60 per cent. of sea water, is a needlessly high limit, the attainment of which is not necessary to a general program of securing inoffensive and reasonably clean harbor waters. A much smaller quantity will, in fact, suffice.

It is my belief that the significance of this matter has not been well understood by many of those considering this question; and indeed has been confused needlessly with assumptions as to requirements for major fish life and a desire to provide a very liberal margin of safety in guarding against offensive odors.

Deoxygenation of the waters overlying putrefying sludge deposits has complicated quite seriously many of the limited data now available upon this topic.

In again taking up this question below, I shall go more into detail, but it appears to me that many writers upon this question have not carefully noted the absence of putrefactive odors where dissolved oxygen has fallen to much smaller figures than stated in the above proposed standard.

Metropolitan Sewerage Commission's Program

The essence of the program which the Commission has developed deals particularly with the following decisions:

1. Suspended particles of sewage origin readily visible to the naked eye should be removed from practically all of the sewage before it is discharged into any of the adjoining waters.

2. It is futile to attempt to make the water in New York harbor and adjacent watercourses of a hygienic quality suitable in a raw condition for bathing, except by a thorough and expensive sterilization. Even if the dry-weather flow of all sewers were removed from the harbor waters they would still fall far below clean-water standards necessary to insure safe bathing and the safe raising of shell-fish. This is owing, of course, to the overflow discharges at times of storms from the existing sewers, which are built to carry both the domestic wastes and the rain-water falling upon the streets, roofs of buildings, areaways and unoccupied land.

3. Dispersion or dilution of the flow from existing sewer outlets into neighboring watercourses results in many cases in faulty mixing of the sewage with the harbor waters. In some cases this inadequate mixing of sewage and harbor waters can be corrected without great difficulty by releasing the sewage from pipes laid on the stream

bed so that there will be a prompt mixing of the sewage with sufficient moving water. In other instances the relative proportion of sewage to clean water available for dilution is such as to preclude an entirely satisfactory solution of the problem without removing the sewage in an interceptor to a point somewhat distant from the present sewer outfalls.

4. Deposits of sewage sludge on the bottom of the harbor and certain of the adjoining watercourses, particularly in the vicinity of slips near large sewer outlets, rob the harbor waters of much of their atmospheric oxygen and lessen materially the quantity of clarified sewage that can be satisfactorily disposed of by dilution.

5. The disposal by dilution of the city sewage into neighboring waters in a carefully considered manner is the most suitable way of disposing of a very large portion of the sewage of New York City.

6. The proposition of collecting all of the sewage of New York City and discharging it through tunnels at sea off the southern coast of Long Island has been decided by the Commission to be inadvisable on the ground of excessive cost as compared with other procedures which would give satisfactory results.

7. A central plant for the application of the sewage of New York City to land for purposes of sewage farming is also barred on the ground of excessive cost.

8. Disposal of the sewage by filtration in plants of the intensive type, such as sprinkling filters, is likewise considered unjustifiable on the ground of the cost which would be involved by works so built and so located as to be inoffensive to the neighboring property owners.

9. The basic feature of the procedure recommended by the Commission is to treat the sewage of each natural drainage district in accordance with the individual requirements of this district. This allows use to be made of the dilution method for the digesting and disposing of the clarified sewage up to the full limit of practicability, if such limit should be needed, in any or all of the subdivisions which you have made of the area of the Metropolitan Sewerage District. It also has the advantage of allowing the construction work to be carried on piecemeal; work may be begun where it is most needed, and necessary improvements need not then be delayed until funds can be raised and construction work accomplished for a large central disposal project.

10. It is the conclusion of the Commission that the needed improvements in disposing of the sewage of New York City should be carried out under the control of some central authority which would see that progressive construction work is executed in conformity with a comprehensive design looking well to the future needs of the Metropolitan District as a whole. Such a central authority would also see to it that the work is directed first to solving problems which are in greatest need of attention and in general in coördinating the construction procedures with the financial aspects.

General Endorsement of Commission's Program as Above Stated

Dealing in a broad way with the recommendations of the Commission as outlined in the foregoing ten paragraphs, and passing by for the present the question of the residual quantity of dissolved oxygen and the consequent amount of purification to maintain the standard adopted, I am clearly of the opinion that the recommendations are sound.

I take it that the citizens and taxpayers of New York City are ready to adopt improved sewage disposal procedures which will correct objectionable putrefactive conditions and in general to proceed on a program whereby visible objects of sewage origin will be removed from the sewage before its discharge into the harbor waters.

I am equally convinced that this community does not desire and will oppose the expending of such large sums of money as would be required either for pumping all of the sewage of New York to a point of disposal in the deep waters of the ocean or for applying it to many square miles of farm land upon Long Island, or for filtering and oxidizing the sewage so that its purity would be comparable with that of the waters of the Hudson river above New York City.

The problem is essentially that of constructing works for clarifying the sewage by means of screens or by subsidence in settling tanks, or by both, and of distributing the partially clarified sewage so that it will be properly mixed with an adequate quantity of water. With this done I am satisfied that adequate and proper results will be obtained, although I am aware that most careful attention must be given in some instances to lessening the effect of sewage deposits that are at present seldom or never dredged and in other instances to diverting the sewage for a greater or less distance from its point of origin to a suitable place for its treatment and the mixing of the treated sewage with sufficient diluting water.

I am strongly in favor of the erection of a central authority which shall direct in a businesslike way the progressive improvements that are needed in solving the sewage disposal problems of New York City so as to harmonize the work that is done year by year in accordance with a comprehensive and systematic plan. This, in my opinion, is a necessary element to conform with the needs of efficient city planning. Haphazard execution of disjointed plans is bound to lead to unsatisfactory results as well as to waste of the public funds. It is necessary that the administrative body controlling the sewage disposal policy of the city shall consider the requirements and welfare of the city as a whole.

Reverting now to the terms of the inquiry which you have made of me, I take it that what you have asked may be briefly stated as follows:

Is our knowledge now sufficiently definite on:

A. Present shortcomings of the method of disposing of the sewage of New York City; and

B. Corrective measures;

as to warrant the adoption of a general plan for disposing of the sewage of Greater New York; or are the advances in the future likely to make present designs injudicious either from the standpoint of efficiency or of cost?

Without any hesitancy I can answer your inquiry by saying that the present state of the art of sewage disposal is such that it is feasible to proceed with plans for the progressive improvement of methods of sewage disposal which will lead at reasonable cost to the dispersion of suitably clarified sewage in adequate volumes of relatively clean harbor water.

Future developments in the art of clarifying sewage will no doubt result in securing higher efficiency for a given investment, other things being equal, than can be now obtained. However, it is my belief that designs made now for devices for settling sewage and disposing of the resulting sludge will not for many years become obsolete.

I am convinced that the time and conditions will never arrive when any great part of the sewage of New York City will either be sent to sea, applied to land or to filters of any type.

My task, therefore, resolves itself into a recital, in the first place, of why a central plant for deep-sea disposal, land treatment, or filtration, will not be needed for the whole city, and secondly, of my views as to certain features of the progressive improvement of the present sewage disposal methods of each of the natural drainage areas of New York City.

Undesirability of Deep-Sea Disposal at a Central Point

In its Preliminary Report I, dated September, 1911, the Commission outlines a proposition which it considers practicable but not necessary for delivering the sewage of Greater New York to large storage reservoirs in the neighborhood of Barren Island; whence the sewage would be discharged on the outgoing tide through tunnels, 4 in number, 18 feet in diameter, and leading to a point some 3 miles north of the Ambrose channel light vessel and about 5 miles southeast of Rockaway point. The investment cost is stated to be estimated as "not less than $140,600,000." In this sum no reference is made to the annual cost of operation and maintenance, which would be a very substantial item, owing to the necessity of pumping.

Such a method of disposal of the sewage of New York City would have a precedent in the practice at Boston. There, however, the amount of clean water available for the dilution of sewage along portions of the water front of the inner harbor was merely nominal as compared with that which is available in most of the open watercourses in and around New York City.

I consider that it would be possible to apply this method, if it were needed, to obtain satisfactory results in New York. I have noted the reference of the Commission to the probable offensiveness of the sewage which would have passed through such a long length of tunnels as to bring about a state of decomposition that would make it far more offensive than fresh sewage. While this point is well taken, I consider that by means of aeration and the use of sterilizing agents properly applied, the decomposition of the sewage while in transit could probably be so arrested as to prevent serious offense resulting at the outfall, though not without incurring a material expense in so doing.

But the principal point here to be noted is that there is no need whatever of going to the expense of adopting deep-sea disposal for all of the sewage of New York, with its burden for interest, sinking fund and operating expenses, based on your estimates, amounting to not less than about $1.50 per annum per capita. Suitable disposal for the New York problem can, as the Commission states, be secured for far less expense than this.

It is also to be pointed out to the idealist who wants no vestige of impurity in the waters of New York harbor, that even the diversion of the entire dry-weather flow of the sewers of New York and a substantial portion of the storm flows thereof would not result at all times in a perfectly clear harbor water. This would be owing partly to the storm flows from the sewers, which at times would be far in excess of capacity of any tunnels which the city would be able to build; partly to the soil wash and swampy discoloration brought to the harbor by the Hudson river at times of flood; and partly perhaps to the sewage of cities whose disposal methods would be entirely beyond the control of the City of New York.

While the clear water from the sea would be an attractive factor at certain times in the watercourses around New York, it is entirely impossible to secure it at all times. Judging by experiences of those who live on the muddy watercourses of our southern and western rivers, the ordinary feeling is that it is not worthy of serious consideration to figure on doing anything more than to free the New York harbor waters of readily visible signs of their pollution by sewage wastes.

In my judgment it is needless to discharge all the sewage of New York City into the ocean at a central point and it is perfectly safe for the officials of this city to drop the question for all time.

UNDESIRABILITY OF APPLYING THE SEWAGE OF NEW YORK CITY TO SEWAGE FARMS ON LONG ISLAND

Since the earliest days of the water-carriage method of removing domestic wastes through underground channels there has been in nearly all large communities much discussion at intervals of the deplorable waste of the manurial value of the contents of city sewers. To those who do not take the trouble to look carefully into the matter this question will no doubt continue to be a vexation.

Our sewage contains about one part of total organic matter in 5,000 parts of water. If the organic matter could be treated and made available as a fertilizer, without having to go to the expense of dealing with the water used for transporting the sewage through the sewers in the city streets from the point of origin to the point of disposal, this question would assume entirely different proportions.

The late Dr. Thomas M. Drown, formerly Chemist of the Massachusetts State Board of Health, and later President of Lehigh University, in discussing this question employed a very apt illustration. He said that several million dollars worth of gold exist in the soil upon which the city of Philadelphia is located. It is impracticable as a business proposition, and for all time to come will continue to be so, to extract this gold. So it is with the question of extracting the manurial constituents of sewage from the relatively enormous volumes of water with which they are mixed.

In its Preliminary Report I, dated September, 1911, the Commission states that an area of about 175 square miles of land would be needed if disposal by sewage farming or broad irrigation were adopted, on the basis of 12,000 gallons of sewage per acre per 24 hours, and that the tract of land nearest to New York of suitable elevation and proper quality of soil which can be found is in the stretch from Amityville to Quogue, a distance of some 50 miles from the city. The report further states that such a project would cost more than $153,000,000, of which about $140,000,000 would be for the collection and delivery of the city sewage to the sewage farms. While these estimates provide for a capacity sufficient to take care of the dry-weather sewage flow from a population of about 9 million people, estimated to be reached by New York City in 1940, they do not provide for any reserve area, which, in my opinion, would be needed for receiving the sewage at times of prolonged rainfall, or for the purchase of a strip of land around the sewage farms so as to guard against complications, due to odors, from neighboring property owners.

I have had occasion to look into the question of the use of sewage farms at various places both in the arid districts of America and elsewhere in this country, as well as in Europe. Where there is ordinarily an abundance of rainfall sewage farming on a large scale has not proven a sanitary success, owing to the difficulty during periods of heavy rainfall and while harvesting the crops of preventing the sewage from flowing to the nearest watercourse in an untreated condition. Complications have arisen not only with riparian owners along watercourses below sewage farms, but difficulties have also been encountered from odors arising from the decomposition of "pooled" sewage that accumulates at certain seasons on clogged land that becomes "sewage sick," even in instances where the soil was originally fairly porous.

Sewage farming is prompted by one or both of two objects. One of these is to utilize the fertilizing value of the sewage and the other is to take advantage of the irrigating properties of the water content of the sewage.

Experience abundantly demonstrates that with the dilute sewage of America the cost under all ordinary circumstances of delivering sewage to suitable sites for sewage farming far exceeds the value to be derived from the sewage from its combined fertilizing and irrigating properties.

I looked into this question with some care a few years ago at El Paso, Texas, and found that it would cost more to deliver the sewage to suitable areas for a city sewage farm than would be the total cost of subjecting the sewage to purification in modern intensive treatment works located fairly close to the city. The absence of well-developed practicable working sewage farms in the vicinity of any sizable American city, even in the arid regions, indicates that sewage farming carries a financial burden far beyond any possible benefits to be derived from the sewage itself. Citations need to be made only to the abandonment some ten years ago of the sewage farms at Los Angeles, Cal., in favor of disposal through an outfall sewer to the Pacific ocean, to a similar fate in the near future for the Pasadena sewage farms and to the absence during a period of more than 20 years of any successful utilization for irrigating purposes of the flow of the main outfall sewer of Denver, Col.

Reference is frequently made to the sewage farming experiences of sizable cities of Europe, particularly Paris and Berlin. At the latter city conditions were unusually favorable as to character of soil, price of land secured many years ago and the low mean rainfall of some 25 inches, making the irrigating properties of the sewage of substantial worth. Even under European conditions it is significant to note the substantial abandonment of the largest sewage farm in England, namely, at Birmingham; the adoption of sprinkling filters for large suburban areas around Paris and Berlin as noted by the large installations at Mount Mesley and Wilmersdorf, respectively. Furthermore, the city of Paris itself, instead of increasing its sewage farms, is adopting sprinkling filters, the first installation having been completed about a year ago.

Even at Berlin, where conditions are probably the most favorable of any place, the total gross income exceeds but slightly the outgo for operation and maintenance, leaving but a nominal sum available for interest charges.

A large sewage farm on Long Island could advantageously receive city sewage for a much smaller number of days in the year than is the case at Berlin. This means either that the sewage would be applied to the land in quantities and at times that would be prejudicial to the raising of crops, with the attending likelihood that over portions of the area it would accumulate, putrefy and give off offensive odors; or that it would be diverted to neighboring watercourses for days at a time; or that it would be necessary to provide immense storage reservoirs in which to retain the sewage for weeks and probably months at a time, as is the case at Berlin and at San Antonio, Tex., so as to use it only when the application would be either advantageous or permissible in the interests of crop raising.

Taking into account the enormous expense involved, the unreliability of sewage farming compared with numerous other available methods of sewage treatment, I am convinced that there is absolutely no opportunity for sewage farming to become worthy of practical significance in solving the sewage problem for New York.

IMPRACTICABILITY OF A CENTRAL PLANT TO TREAT ALL THE SEWAGE OF NEW YORK CITY BY INTENSIVE PURIFICATION METHODS

If New York were an inland city situated on a comparatively small stream so as to necessitate the use of treatment works to oxidize the soluble and non-settling organic constituents of its sewage, the present state of the art of sewage disposal clearly indicates that the most practicable method would be to apply settled sewage to sprinkling filters so as to oxidize the sewage sufficiently to make it non-putrescible.

This is the method adopted at Birmingham, England; for the suburban areas around Paris and Berlin; at Baltimore, Md., Atlanta, Ga., Columbus, Ohio, and practically every sizable city in America that has had occasion recently to figure seriously upon disposing of its organic wastes where the dilution method of dispersion in a relatively large watercourse was not available.

In its Preliminary Report I, dated September, 1911, the Commission summarizes its studies indicating that it would cost approximately $141,000,000 for treatment works of the type above mentioned located on Barren Island of a size to take only the dry-weather flow of a population of 9 millions of people, estimated to reside in New York City in 1940, and does not recommend this solution of the problem.

It may be that in the future some method may be developed through the use of oxidizing chemicals combined with aeration so as to be able to secure an equal effect at less expense than by the use of sprinkling filters. In my opinion it is useless to attempt to discuss such possibility of the future art of sewage disposal as applied to local problems, partly on account of lack of information to suggest the nature of future developments, but principally on account of the undesirability of adopting any method of central disposal for the sewage of New York City. In a word, I agree fully with the conclusions of the Commission that sprinkling filters at a central point for treating all of the sewage of New York City would involve an expense that is unjustifiable.

As the years go by it is quite possible that in some districts special methods of oxidizing the sewage may be necessary in adequately taking care of the sewage of an increased population, but a central plant, in my judgment, is entirely out of the question during the next generation, and probably for all time.

Sprinkling filters, while the cheapest method of securing a sewage effluent which will not putrefy, are liable to involve nuisances from the standpoint of odors. If the sewage could be kept in a fresh condition, as is the case at the five-year-old plant at Reading, Pa., odors would rarely if ever be noticed as much as 100 yards distant. On the other hand, at Columbus, Ohio, and Baltimore, Md., a zone surrounding the plant one-fourth mile in extent has been found at times to be insufficient to prevent odors from reaching residents living beyond that limit, owing to the advanced stage of decomposition to which the sewage has progressed before it reaches the sprinkling filters. Contact beds, per cubic yard of filtering material, operate at rates about one-third as high as do sprinkling filters, but the likelihood of odors is much less. This is because with contact beds the sewage is not thrown into the air from nozzles in the form of spray, but is applied at the bottom of the filter beds and not allowed to come to view at the surface.

Mention is made of these latter features having in mind that while a central filter plant will not be needed for the New York sewage, it may be found proper in certain areas to supplement the work of fine screens or settling basins previous to dispersion of the sewage in the neighboring watercourses.

Synopsis of Program Adopted by the Commission

Having considered and concurred in the conclusions of the Commission as to the great cost and lack of necessity of disposing of the sewage of New York City at any central plant regardless of type, I shall now proceed to state my views on the program laid down by the Commission for disposing of the sewage of the several natural drainage divisions of Greater New York into which you have divided the area and for which you have proposed treatment methods depending upon various local conditions and factors.

It is needless to repeat from your reports in great detail a description of these methods of treatment and the areas to which it is proposed to apply each method. But for the sake of explicitness I shall briefly sum up in tabular form some of the principal data, as they are set forth in your reports.

The area, population, number of sewer outlets and the watercourses into which these outlets discharge are all of much interest to the reader of these reports, and I have endeavored to summarize your findings in this regard in Table XX.

TABLE XX

City Divisions and Discharge Points for Sewage

Division.	Subdivision.	Area in Acres.	Population.				Proposed Sewer Outlets.	
			1910	1940 (Estimated).	Per Acre. 1910	Per Acre. 1940 (Est.)	Number.	Discharge to
Jamaica bay..	Brooklyn................	19,900	270,000	619,000	14	32	1	Outlet island.
	Queens..................	30,900	81,000	290,000	3	9	1	Jamaica bay.
Upper East river and Harlem.....	Harlem................	12,100	995,300	2,105,800	81	173	1	Hellgate at Wards Isl. (at Hunts Point).
	Eastern Bronx...........	10,600	30,300	73,600	3	7	1	Hell Gate at Wards Isl. and East River.
	Northwestern Queens......	3,100	10,000	28,500	3	9	1	Hell Gate opposite Wards Island.
	Corona-Flushing..........	16,800	62,200	179,800	4	11	1	East river at College Point.
	Northwestern Queens......	5,900	8,000	22,900	1+	4	1	East river opposite Throg's Neck.
Richmond....	Quarantine..............	817	7,461	68,470	9	84	1	Narrows.
	Stapleton................	1,714	19,393	132,255	11	77	1	"
	Livingston...............	959	11,433	88,575	12	92	1	Kill van Kull.
	West New Brighton.......	5,056	17,491	286,220	3	51	1	"
	Elm Park................	632	8,542	58,100	13	92	1	"
Lower Hudson, Lower East river and bay........	Hudson..................	5,600	726,000	1,470,000	130	263	...	Hudson river.
	Manhattan, Lower E. side.	1,737	680,500*		393*			Outlet island.
	Brooklyn, northwestern....	5,790	732,313*		127*			
	Western Jamaica bay......	19,000	343,000*		18*			

* = 1915.

A marked variation is found in the volume of water available for the absorption and digestion of sewage reaching the various sections of New York harbor. As a matter of convenience for reference I have copied in Table XXI the data given on page 26 of the Preliminary Report VI of the Commission, dated February, 1913; and to this I have added a memorandum indicating roughly whether or not sewage deposits now pollute the main channel or shores of the respective watercourses or subdivisions of the harbor:

TABLE XXI

VOLUME OF WATER IN MILLIONS OF CUBIC FEET

Division of the Harbor.	Below Mean Low Tide.	Tidal Prism.	Net Ebb Flow in 12 Lunar Hours.	Condition of Bottom.	
				Channel.	Shores.
Harlem river	285	148	15	Polluted.	Polluted.
Hudson river, Battery to Mt. St. Vincent	12,330	1,697	1,087	Clean.	"
Upper East river	5,512	1,869	....	"	"
Lower East "	4,174	552	100	"	"
Upper bay	12,970	2,541	1,283	Polluted.	Polluted.
Newark bay	1,542	1,071	105	"	"
Kill van Kull	728	150	88	"	"
Jamaica bay	2,029	1,977	....	Clean.	Clean.

American engineers for many years have been accustomed in their deliberations on problems for the disposal of sewage by dilution to note the available quantities of water expressed in terms of cubic feet per second per thousand population connected with the sewers.

Without attempting to enter into the question of the accuracy either of available quantities of water or of estimates of future population, I give in Table XXII certain dilution factors deduced from the data of Tables XXI and XX.

These computations show at once that the principal problems of sewage disposal relate to the Harlem river, the Lower East river and Jamaica bay, and not to any substantial extent, for the next generation, to the Hudson river, Upper bay or Kill van Kull.

TABLE XXII

DILUTION FACTORS IN CUBIC FEET PER SECOND PER 1,000 POPULATION

Section.	1910		1940	
	Tidal Prism.	Net Ebb Flow.	Tidal Prism.	Net Ebb Flow.
Harlem river	4.15	0.42	1.94	.20
Hudson "	37.9	24.3	19.6	12.6
Upper East river	230.0	.....	64.6	.....
Lower " "	6.19	1.09	3.85	.70
Upper bay	110.0	55.6	62.8	31.6
Newark bay	232.0	22.8	120.0	11.8
Kill van Kull	67.0	39.5	24.1	14.2
Jamaica bay	126.00	.....	50.0	.....

These figures of both tidal prism and net ebb flow dilutions are not of themselves a measure of the condition of the water or the quantity of sewage which can be digested. The net ebb flow is by no means all clean water.

The effect of the tidal prism is to make the sewage received by the waters oscillate back and forth, the water containing the sewage becoming more polluted until it has reached the point where the outflow of sewage with the tidal water balances the sewage supply. Also the water reaching the lower sections, such as the bay, from water such as the Hudson river, is already polluted. On the other hand, reaeration of the harbor water is a helpful factor, affording a supply of oxygen to replace in part that absorbed through the digestion of sewage matters.

While dilution factors thus complicated by variability of quantity and quality of diluting water and by the uncertainty of the beneficial effects of reaeration are only a rough guide, these figures of this Table XXII, taken together with our knowledge of the pollution as given by the oxygen content in Table XIX, throw some light on the necessary purification for present and future increased sewage flow.

EFFICIENCY OF METHODS OF SEWAGE TREATMENT

As to the efficiency of various types of sewage treatment works, I have noticed the percentages of removal which it is assumed may be obtained as given on page 30 of your Preliminary Report VI, dated February, 1913. I believe these percentages of removal, as you have estimated them, are reasonable deductions from present data and can be obtained in practice in plants of reasonable cost. In fact, I note that the percentages which you have assumed for the various devices do not differ materially from the estimates I made in conjunction with Mr. Rudolph Hering in 1906 in a report on the Chicago Sanitary District for the International Waterways Commission, and which figures I reproduced in my book on "Sewage Disposal," 1912, page 741.

In Table XXIII there are recorded comparative percentages of removal of suspended matter and organic matter, respectively, to be expected of the different treatment methods, as given by your Commission and myself:

TABLE XXIII

Treatment Method.	Suspended Matter.		Organic Matter.	
	Met. Com.	G. W. F.	Met. Com.	G. W. F.
Screens (fine)	15	15	15	10
Sedimentation	60	65	30	30
Chemical precipitation	85	85	50	50
Sprinkling filters	90	85–90	70	65–70

THE SIGNIFICANCE OF THE DIGESTION OF SEWAGE SLUDGE AND THE ABSORPTION OF DISSOLVED ATMOSPHERIC OXYGEN IN SLUDGE DECOMPOSITION

In regard to percentages of removal of organic matter, the significance in a practical way of the withdrawal of atmospheric oxygen from the overlying water as deposits of sludge putrefy upon the bottom of watercourses has pressed itself forward for attention since most of the data were obtained for arriving at the conclusions embodied in Table XXIII. For instance, the removal of organic matter by sedimentation, given as 30 per cent., is probably a little high judged by the "atmospheric oxygen consumed" in tests of short duration when comparing the corresponding data obtained from settled and unsettled sewage.

Notwithstanding the data obtained by Dr. Lederer, of Chicago, and Mr. Hoover, of Columbus, on atmospheric oxygen consumed, as given in my book on "Sewage Disposal," 1912, page 421, I am inclined to think that substantially different results might have been obtained if the tests were continued for a longer period in the instance of the unsettled sewage; so that account might be taken of the deoxygenating effect of suspended particles which slowly respond to the effect of septicization and produce decomposition products of an unstable kind. Without doubt the larger particles of suspended organic matter contain relatively less putrescible matter that readily undergoes bacterial decomposition than is the case either with soluble or very finely divided suspended solids. But in practical sewage disposal problems, where the dilution method requires improvement, it is ordinarily found that there are some places within a stream where sludge deposits accumulate and gradually undergo decomposition with attending consumption of oxygen from the overlying waters. In particular must it be borne in mind that sludge deposits during the winter may remain relatively dormant and become active with the arrival of warm weather for the consumption of oxygen from the overlying water at times when there is least oxygen available.

Thus the sludge deposited uniformly day by day on the river bottom will, during the cold weather, inactively accumulate; and with the advent of higher temperatures in summer the aggregate volume of sludge piled up will act in an intensified manner.

I have no definite data at hand to indicate the effect of temperature upon the digestion of sewage sludge accumulated upon stream beds, but some insight may be obtained from the relative quantities of gas liberated from the sludge accumulations in a small septic tank studied at Worcester, Mass., some years ago, as follows:

TABLE XXIV

PERCENTAGE WHICH THE VOLUME OF GAS PRODUCED EACH MONTH IN SEPTIC TANKS IS OF THE ANNUAL

January	30	July	140
February	62	August	167
March	48	September	170
April	51	October	116
May	100	November	115
June	148	December	65

In this connection reference is further made to my book, pages 65-71 and pages 479-82, dealing especially with the comparative slowness with which solid organic matters decompose as compared with dissolved organic matter, and it is suggested from the Lawrence data that gasification does not occur in sewage free of sludge.

I have also noted in this connection the statements of Messrs. McGowan, Frye and Kershaw as given in Vol. II, Appendix to the Eighth Report of the Royal Commission on Sewage Disposal of Great Britain, page 130. After studying the rate at which atmospheric oxygen during the period of five days was absorbed by original and paper-filtered samples of sewage from 22 different places, the conclusion is drawn that—

> "We think it may be taken that sewage liquors and effluents generally, with their suspended solids, will take up about twice as much dissolved oxygen, in periods up to five days, as the liquid portion alone will do."

It is not necessarily to be deduced that the final or absolute oxygen consumption, however, will be in the same proportion.

In the absence of detailed data on this question only a tentative opinion can be formed. But there is enough information at hand to indicate the need of much more study of these features than has been given hitherto. And in the meantime, I attach much weight to the possibility that the deoxygenating effect of sludge is materially greater than its proportionate amount of organic matter, and that the removal of sludge by sedimentation will effect an improvement more than proportionate to the weight of organic matter removed.

Further consideration on the same line leads me to the thought that the removal of sludge deposits by dredging may be of value. I understand that a study of methods and costs of such sludge removal has been made by the Commission.

PROBABLE FUTURE OF VARIOUS SEWAGE TREATMENT METHODS

You have asked my opinion on the probable future changes in sewage disposal procedures. I shall discuss the various topics briefly in the light in which I now regard their probable future standing:

Oxidation Methods

These procedures are aimed essentially at the prevention of putrefaction of sewage matters and hence deal particularly with soluble and colloidal constituents of sewage.

Dilution. This is the prevailing method all over the world for securing the oxidation of soluble or non-settling sewage matters wherever there is ample water to bring about satisfactory results. Without attempting to state precisely the digestive capacity of New York harbor, it is sufficient to say that for all time to come it will oxidize under suitable conditions the clarified sewage of many millions of people. Departures from this method will be required solely in areas where the sewage cannot readily be delivered to bodies of water of sufficient volume.

The dilution method has usually been applied in this country under improper conditions. Clean watercourses can be maintained with the dilution method and past shortcomings should not militate against the advantages and economies of utilizing the digestive capacity of the harbor waters.

Filtration. Where sewage cannot be applied to diluting bodies of water on account of the distance from same and the expense of delivering the sewage, filters will undoubtedly continue to serve a useful purpose. I believe the future will show no radical departures in the efficiency or cost of either sprinkling or contact filters. The tendency will be towards improvements in the design of certain details. I am clearly of the opinion that filtration has no future so far as relates to the main volume of New York sewage.

For certain areas, particularly those now comparatively sparsely populated, I think that a number of filter plants installed and operated for a period of 10 to 20 years may in the end prove cheaper, even if then abandoned, than would be the case if at the outset the general plan should embody the execution of collection works for a central plant with several subdivisions.

I look for improvements in the preliminary treatment of sewage to lessen materially the odors sometimes attending sprinkling filters. For certain thickly populated districts I believe contact beds are entitled to careful consideration.

The lessening of odors requires primarily the prevention of putrefactive conditions becoming established in the unfiltered sewage by aeration, oxidizing chemicals and probably to some extent the application of sewage so as to minimize the opportunity for wind action to transport sewage spray.

Aeration. I look upon aeration as a promising means of guarding against putrefaction. If conditions arise where it is necessary to deal with sewage which has to some extent undergone putrefaction, I consider it possible that organic matter to a limmited extent may be reduced through oxidation by air. Except for limited quantities of unstable organic substances, aeration cannot be counted upon as an oxidizing agent in practice. It provides molecular oxygen, whereas the bulk of the organic matter of sewage is oxidized only by the atomic oxygen of certain powerful oxidizing agents, or the slow oxidization effected through bacterial action.

The function of aeration is essentially one of artificially prolonging the period of decomposition of sewage on an inoffensive aerobic basis. It may be that conditions will arise where the occasional application of air by artificial means will permit the dilution method to be employed, whereas without aeration or some similar treatment the dilution method would present objectionable and offensive shortcomings.

On the score of cost the aeration method for general use does not look promising; and this is particularly true of the New York conditions where the sewage oscillates back and forth for a period of time that makes a demand on the atmospheric oxygen greater than is the case with many flowing inland streams.

Oxidizing Chemicals. The cost of applying such chemicals as liquid chlorine and hypochlorite of lime or of soda is prohibitive on account of the relatively small amount of organic matter that is oxidized. The true function of such agents is the killing of bacteria, and within certain limits they are useful as a preservative for sewage to prevent decomposition rather than to effect complete ultimate oxidation of the non-settling organic matters.

Electrolytic Treatment. A good deal is claimed from time to time for the economical advantages derived from the application of electricity in various types of electrolytic cells in oxidizing the organic matters of sewage. In particular is this claimed where the current may be applied to sea water. While improvements in this direction may be possible, I do not believe that they are promising enough to warrant consideration of electrolytic treatment as a substitute for the dilution method.

The electrolytic production of chemicals to precipitate certain colloidal and other non-settling organic matters may prove desirable in the future and worthy of adoption under some conditions. This method would be used, however, in conjunction with settling tanks, and could be employed supplementary to such tanks without requiring material changes in the design of tanks built for plain sedimentation alone.

Clarification

The purpose of clarification devices is to prevent unsightly sewage solids appearing in the diluting water, or the formation of sludge banks in watercourses.

Fine Screens. Fine screens afford the cheapest way of removing visible objects of sewage origin from the waters receiving sewage where such screening treatment alone is sufficient for obtaining satisfactory results. Under conditions where the limit is at times reached in the amount of clarified sewage which a watercourse will oxidize satisfactorily, settling tanks as a general rule are cheaper to install than screens, because for a given cost they will remove a greater quantity of organic matter. Where screens will suffice for a term of years, say ten or more, it is quite possible that it will prove economical to install screens first, to be followed later by settling basins as occasion demands.

American experience with fine screens is quite limited and not altogether satisfactory, owing to the devices requiring much attention and repair. This has meant not only expense, but also serious interruptions in continuity of service.

Screens are employed to much better advantage in Europe, particularly in Germany. At Dresden, Frankfort and Hamburg experiences demonstrate on a large scale that it is feasible to operate moving plate screens with an opening as small as 0.04 inch. At present the so-called Reinsch type of screen, as installed at Dresden, seems to be most popular. It is of the disc type with slots about 0.085 inch wide and 1.25 inches long.

As fine screens come into service in America I look for marked improvements in continuity of service and freedom from expensive repair costs. I do not believe their efficiency will be any greater than that indicated by European evidence unless it should result from applying to screens sewages which are fresher and less comminuted than has been the case at Dresden, Frankfort and Hamburg.

Settling Tanks. Sedimentation for a two-hour period at the average rate of sewage flow will give as good results as it is prudent to obtain from sedimentation. For local conditions I favor single-story tanks with hopper bottoms, as it is undesirable to septicize the sludge at its point of origin.

The construction of settling tanks along the New York water front presents some difficulties on account of the high cost of ground, complications from salt water backing into the sewers at high tide and the necessity of caring for storm flows. I believe these difficulties can be overcome by careful engineering study.

Fine Screens vs. Settling Tanks. My views have been already indicated in the foregoing paragraphs. But as the question has much significance here in New York, I will state that, in my opinion, screens are preferable to settling tanks only where it is desirable or necessary to remove only relatively large sewage matters in suspension. Where settling solids would form deposits in the watercourses if screening alone were adopted, to install settling tanks will prove wiser than to install fine screens. Available data in this country are now too meager to allow fine lines to be drawn in this comparison. For problems of this magnitude special study should be given before construction, not only of the relative merits of the two systems as a whole, but also of the local conditions at each main sewer outlet or groups of outlets which can be conveniently united. Both screening plants and settling plants can be operated for treating fresh sewage without creating any nuisance.

Chemical Precipitation. The use of coagulating chemicals has been known for 50 years as a helpful adjunct in removing particles of suspended matter which are so fine that they will not subside in ordinary settling tanks. The expense of the added chemicals and the large increase in the volume of the resulting sludge is such that as a general proposition chemical precipitation is not worth while.

There may be exceptional conditions where plain sedimentation might be at times inadequate preparatory to the discharge of sewage into some arms of the harbor, and further purification then resulting from the application of chemicals might be wise.

Sludge Disposal

In the clarification of sewage there results in all cases a substantial quantity of solid matters more or less mixed with water and ordinarily spoken of as "sludge." Experience at other large seaport towns employing sewage treatment works, such as London, Glasgow, Manchester and Salford, demonstrates conclusively that the barging of sludge to the open sea is the cheapest way of disposing of the sludge without nuisance.

As above stated, I do not favor septicization of the sludge along the water front in the thickly inhabited districts of New York. In this respect I agree with the Commission.

Cases may arise in isolated areas removed from the water front where barging to sea will not be desirable. In such cases I advise the consideration of two-story tanks of the Imhoff type, with the drying of the sludge on drying beds so that the residue can be carted off readily.

Use for Fertilizer. For more than 50 years efforts have been made to employ sewage sludge economically as a fertilizer. Rarely if ever has the result been a commercial success when operations were conducted on a large scale. I do not look for any substantial change in the future, although sewage sludge may perhaps be employed as a "filler" for fertilizers. In such event it is safe to assume that the users of the material coming from settling tanks would be willing to prepare it for their processes, and if this is so it would simply mean that New York would be relieved of operating barges to sea up to the limits to which sludge is diverted to fertilizer purposes. While some slight saving in the operation of barges may be accomplished I do not look for any substantial compensation to the city from fertilizer manufacturers who might use the sludge as filler.

Incineration. I am aware that at Frankfort, Germany, sewage sludge is freed of water by centrifuging and the application of heat in revolving drums, so that the dried sludge may be burnt with other city refuse in an adjoining municipal incineration plant. While this procedure may have a future for inland cities, the expense will never be reduced to a point where this method will displace barging to sea for the sludge of a large seaport town.

Destructive Distillation. In a small way there are some data available as to the production of combustible gases and coke by the dry distillation of sludge. The cost of removing the water is so great that the future will never see this treatment become commercially feasible.

Sterilization. With the existing system of combined sewers, without any possibility or necessity of making the harbor waters of a "drinking water" standard of purity, sterilization for the great bulk of the New York sewage need never be seriously considered.

For some of the outlying areas where there are shell-fish layings or bathing beaches I anticipate a resort to sterilization.

Miscellaneous Procedures

From time to time attention is attracted by claims for unusual efficiency or economy or both, resulting from the employment of special types of strainers or other clarifying agents, or the use of oxidizing procedures resulting from the use of new chemicals or of new applications of electricity.

Presumably such claims will be heard from at intervals in the future, and it may be that some of them will produce more effect for a given cost than could now be attained.

I do not believe, however, that the business aspects of the New York problem will ever be materially modified by improvements in methods or devices which may become available.

As time advances a clearer understanding will be obtained as to just what is needed in certain of the subdivisions and the progressive installation of any project as large as the New York sewage disposal problem will give opportunity to adopt in the designs the current improvements which, as above stated, will in all probability relate to minor details rather than to underlying principles.

Conclusions as to Program Being Considered by the Commission

I have carefully considered the program now recommended by the Commission as it is in a general way published. Speaking generally, I agree with the Commission as to the conclusions arrived at for those portions of the harbor where there is an abundance of water for disposing of clarified sewage by dispersion with adequate quantities of water. I disagree, however, with the proposal of the Commission for the Lower East river and Western Jamaica bay divisions to divert the sewage to the proposed "Outfall island" some three miles south of Coney Island. I will briefly outline my conclusions upon these two separate groups of procedures.

A. Agreement on Clarification Program

1. I agree with the Commission that the state of the art of sewage disposal is now such as to warrant the adoption of a definite policy for that portion of the main drainage of the city that is tributary to watercourses containing ample water for dispersion of clarified sewage. By this is meant, of course, the territory having sewer outlets discharging particularly into the Hudson river, the Upper bay, the portion of the East river above Hell Gate, and some portions of the Jamaica bay district.

2. Local factors should determine what form of clarification means should be used. Where screens alone are sufficient no other means need be considered. Where a greater degree of purification is desirable I am inclined to favor simple sedimentation with the elimination of screening.

A close decision of the relative merits of these two clarifying processes is not now called for; it is a matter of careful engineering detail, properly to adapt, in each case, the means used to the conditions of use and the end to be attained.

3. Such local clarification plants can be operated on the banks of the Hudson river, or wherever else installed, without offense to the inhabitants of the neighborhood.

4. I am in accord with the Commission's proposal to disperse the clarified sewage in deep water through submerged outlets, where such dispersal is shown to be necessary.

5. I agree with the Commission that it is proper to consider that the sludge and screenings from the clarification plants can be most advantageously disposed of by barging to sea. Two-story tanks of the Imhoff type as compared with single-story tanks of the so-called Dortmund type are not justifiable on the ground of cost and for the further reason that fresh sludge frequently removed could be more advantageously disposed of at sea than would septicized sludge.

6. As a practical business procedure, I attach importance to the fact that these clarification works can be installed progressively as funds are made available, and would naturally be commenced at points where pollution is greatest.

B. Opinion as to Outlet Island

7. I agree with the Commission that the sewage of the Lower East river district could be satisfactorily disposed of by diversion to a proposed island some three miles south of Coney Island and about one-third of a mile north of Ambrose channel. Such a project as described in Preliminary Report VI is estimated by the Commission to cost in round numbers some $22,000,000, of which about one-sixth is estimated to be owing to provisions made for the sewage from a portion of the Jamaica bay division. A tunnel some 12 miles in length beyond the Wallabout pumping station would require a period of transit such as to make it highly important to aerate and sterilize the sewage

so that it will not have undergone decomposition to a point of producing offensive odors by the time it has traveled to "Outfall island." From the information given as to the mixing of the sewage with the sea water, owing to the action of the breakers in the relatively shallow water, I do not anticipate that clarified sewage would produce deposits or in any other way produce a nuisance.

I do not consider such a site suitable for sprinkling filters, but it is my conclusion, as it is that of the Commission, that such will never be necessary for the sewage of the Lower East river district.

8. While agreeing as to the general feasibility of the "Outlet island project" for the disposal of the sewage of the Lower East river district, I do not agree on the necessity of going to so great an expense in treating the sewage from the area in question.

9. I am of the opinion that the Commission's standard of residual dissolved oxygen is unreasonably severe; a residual quantity of 1.5 cubic centimeters per liter, one-half of the amount of your standard, is safe for adoption under proper conditions. Such proper conditions are that sewage sludge shall not be allowed to accumulate to such an extent as to become a serious factor in absorbing oxygen from the water.

Appended to my report is a memorandum explaining in more detail my views on the question of residual oxygen.

10. My preliminary studies indicate to me that the investment cost of the "Outlet island" project for the Lower East river, as estimated by the Commission in its Preliminary Report VI is about four times as high as sedimentation plants for the same district. The annual charge, fixed and operating, will be for the "Outlet island" project about twice as high as for sedimentation plants.

11. Unquestionably the Lower East river is able to digest the sewage from a large population without being objectionably affected, and I am of the opinion that the East river will absorb the clarified sewage from the populations actually tributary to it for a great many years to come. While the improvement effected by entirely removing the sewage is materially greater than that effected by sedimentation plants, the latter will, on the standard which I consider ample, serve all required ends. They will, too, accomplish at least as much improvement for each dollar expended as would the distant disposal method.

12. These East river clarification plants can be expected to be unobjectionable to public sentiment, as well as the plants on the Hudson river and elsewhere.

13. If at some future time it should prove desirable to divert some of the sewage from areas naturally tributary to the Lower East river to some point such as the proposed Outlet island, such partial diversion can then be more economically effected than an immediate removal of the Lower East river drainage as a whole.

Very truly yours,

OCTOBER 15, 1913.

GEORGE W. FULLER.

APPENDIX TO MR. FULLER'S REPORT

MEMORANDUM OF VIEWS IN OPPOSITION TO THE PROPOSED STANDARD OF A MINIMUM DISSOLVED OXYGEN CONTENT OF THREE CUBIC CENTIMETERS PER LITER OF NEW YORK HARBOR WATER

Having already stated my conclusion that a proper general residual dissolved oxygen content of the New York harbor waters can be safely placed as low as one-half of that proposed by the Commission, I shall now proceed to outline briefly some of the evidence which leads me to conclude that 1.5 cubic centimeters per liter, equal roughly to 2.1 parts per million, or roughly 30 per cent. of saturation for New York harbor water in summer, is a sufficient residual quantity.

As already intimated in this report, consideration of the requirements of fish life and lack of data as to the significance of putrefying sludge deposits have led to conclusions that are not safe deductions from the information available.

Messrs. Black and Phelps in their report to the Board of Estimate and Apportionment, March, 1911, proposed a standard of 70 per cent. residual dissolved oxygen for the New York harbor waters and stated this limit to be needed for major fish life. They stated further that some forms of fish life can exist with a dissolved oxygen content of 30 per cent. of that required for saturation and expressed the view that 50 per cent. is a limit below which a stream may become turbid and noisome and that below 30 per cent. the stream constitutes a nuisance.

I have noted that the Commission has obtained the views of some ten or more sanitary experts with respect to the dissolved oxygen standard, and as stated in the published reports of the Commission all but two or three of these experts have expressed their acquiescence in the minimum limit of 50 per cent. saturation or more. The remaining experts expressed no opinion upon the matter, so that your advisers up to this time have in no instance advocated a residual percentage of less than 50 per cent. of saturation.

Those familiar with bio-chemical activities will agree that theoretically no objectionable offensive products of decomposition can arise in sewage-polluted waters so long as some oxygen exists at all times and in all places in the water and upon the bottom and sides of its container. So much for theory.

In practice it is found that a margin of safety must be provided. Some particles of suspended matter of sewage origin obviously must be present in all sewage-polluted waters (and frequently on stream beds) and that within the interior and upon the sides of these suspended particles it must be recognized that there are present bacteria coming from the abdominal tract of those voiding fecal particles and are likely to continue to live on an anaerobic basis. In particular is this true of organisms within the interior of colloidal or suspended particles, notwithstanding that the exterior surfaces of such particles are surrounded with water containing dissolved oxygen.

Laboratory experiments show in the course of the so-called incubation or putrescibility tests that samples of polluted liquid may turn black and even give off offensive odors while there is still present a measurable quantity of dissolved oxygen. As suspended particles of organic fecal matters (or sludge deposits) undergo bacterial decomposition, they may release products in a soluble or gaseous form which rise to the surface of the overlying water, produce objectionable odors, discolor the water, bringing about these results in the presence of dissolved oxygen.

In small single-story septic tanks it is possible to find the effluent of such tanks containing a high content of dissolved oxygen and at the same time the putrefying sludge deposits give off offensive odors and behave in other ways fairly indicative of septicization. Compare the data in my book on "Sewage Disposal," page 493.

Settling tanks receiving the effluent of sprinkling filters or contact beds likewise may contain a high dissolved oxygen content as the settled effluent is analyzed, but at the same time rapid gasification may be taking place in the deposited sludge upon the floor of the settling basin to an extent that causes gas-lifted particles to appear with the effluent as the latter leaves the outlet of the tank.

In many watercourses there is to be noted in either fresh or salt water a black discolored appearance and the production of more or less offensive odor, even where the overlying water contains a substantial quantity of atmospheric oxygen.

The question then becomes, "What is the margin of safety that it is wise to employ?"

I assume that a substantial portion of the sludge will be removed from the sewage that in the future will enter the harbor waters; also that by dredging and by the exhaustion through bacterial action the organic contents of sludge now found in the harbor and the adjacent watercourses will be materially reduced.

There are some instances where practical observations show on a large scale the relation between dissolved oxygen and the presence or absence of offensive putrefactive conditions. It is such data as these that I consider are the most trustworthy guide to what should be used as a working standard under New York harbor conditions.

It is the experiences of the Lower Thames river in the general vicinity of the outlets of the London sewers which for 30 years have afforded the most comprehensive data in regard to a criterion for residual dissolved oxygen content.

Prior to the commencement of the operation of the Barking creek chemical precipitation plant at the northern London outfall in 1889 and of the corresponding plant at Crossness at the southern outfall in 1891, seriously offensive odors arose, especially during the summer. So bad were these conditions that during the period of construction in the late eighties it became necessary at times to employ hypochlorite of lime and permanganate of soda and other chemicals as deodorants.

For more than 20 years reasonably satisfactory results in the Lower Thames have been obtained as a result solely of the removal of some of the suspended organic matter by chemical precipitation. The bed of the river was thus relieved from the formation of new "mud banks" or sludge deposits, while the old mud banks gradually became inert or were removed by dredging or by scouring velocities at times of flood flows.

The two principal technical advisers in the adoption of the chemical precipitation works for London were Mr. W. J. Dibden and the late Dr. A. Dupre. The latter stated his views on page 88 of Vol. CXXIX of the Proceedings of the Institution of Civil Engineers of Great Britain, as follows:

> "In his experience the amount of oxygen which remained in the river formed the best means of judging the action of the river. If the river was pure, it was fully aerated; if it became foul, the fouler it was the less the amount of aeration, and it was most extraordinary how by means of the oxygen, every foul stream that came into it could be found. When Mr. Dibden and he were at Erith they could, after the first day, find out the hour of the tide by means of the oxygen dissolved in the water, and could find out the sewage stream from Barking by means of the analyses of oxygen absorbed even before the eye noticed it. The oxygen absorbed allowed them, so to speak, to feel the pulse of the river; as long as the oxygen remained about 25 per cent. or 30 per cent. of the possible total there was no fear of any harm."

Mr. Dibden in same publication from which I quote as above from Dr. Dupre, states very clearly on pages 47 and 53 his belief in the adequacy of the chemical precipitation plants in freeing the river Thames from pollution.

In the third edition of Mr. Dibden's book on "The Purification of Sewage and Water," published in 1903, the oxygen content as related to the London problem is discussed at some length on pages 218-20 and on pages 297-300. Here his opinion is made plain that fish life would be in no way interfered with provided the degree of aeration at no time fell below 50 per cent. of that required to saturate the water. While he refers to the need of further experiences, he states that no evil results need be apprehended if the degree of aeration does not fall below 50 per cent., but he does not in any way state a safe minimum from the standpoint of nuisance only. Reference is made to the fish question in terms indicating the belief that there is very little chance of fish thriving in the water when the percentage of aeration falls below 50 per cent., and that when it falls below 30 per cent. it is certain that no fish can live. His viewpoint seems to depend wholly on the question of what is the oxygen content necessary to support fish life and if additional purification were necessary the feasibility of securing that end in the Lower Thames by adopting a final purification for the chemically precipitated London sewage by coke beds operated on a contact basis as devised by Mr. Dibden himself at the testing plant at Barking creek.

Prof. Frank Clowes, the successor of Mr. Dibden as chemist of the London County Council, is more explicit in his views, which are in substantial conformity with those of Dr. Dupre as noted in the testimony of Prof. Clowes given in July, 1903, before the Royal Commission on Sewage Disposal, Fourth Report, Vol. II, Minutes of Evidence, page 113. Asked in question 18,723 whether the almost entire removal of dissolved oxygen from the Lower Thames water brings about actual nuisance, his reply was as follows:

> "I should say that the aeration of the river water would be at its minimum in the immediate neighborhood of the outfalls; for some miles above or below this the average aeration would be something like 20 or 30 per cent. At times it falls to 5 per cent. of the possible, and it is then geeting very near the limit where the oxygen would disappear. When once the dissolved oxygen disappears the change of the organic substances in the river water may become an offensive one, especially in hot weather. It is of a different character in the absence of oxygen and causes offense. This has occurred in the summer in the neighborhood of Woolwich and Greenwich. There was an offensive smell from the river, which, if it had continued, would have caused us to take special remedial steps."

Later in the same testimony, question 18,733, Prof. Clowes states, in answer to a question asking as to the creation practically of a nuisance, that:

> "This occurs very exceptionally indeed. I have only had one case in my own experience."

In October, 1912, Sir Maurice Fitzmaurice, then Chief Engineer of the London County Council, in a special report on the Main Drainage of London, has reviewed an earlier report of his, dated May, 1909, in which with respect to the condition of the Lower Thames he states:

> "The conclusions which I came to in the report to the Main Drainage Committee in December, 1909, in my opinion still (October, 1912) hold good, namely, the state of the river is at the present time not such as to necessitate the immediate further purification of London sewage, and I do not think it will necessitate it for some years to come."

Sir Maurice Fitzmaurice continues his report by referring to special experiences obtained from May to August, inclusive, 1911, when the application of lime and iron was omitted at the northern outfall at Barking. During this whole period

> "no complaint was received as regards the condition of the Thames, notwithstanding that the summer of 1911 was exceptionally hot and the amount of river water coming down was exceptionally small."

These experiments were repeated June to August, 1912, with corroborative results. He recommends that at one of the outfalls operations should be conducted for one year completely without chemicals, which might result in a somewhat less complete precipitation of the suspended organic matters in the raw sewage.

As the London problem has a number of features in common with the one at New York, and in view of the long-continued studies made of the Lower Thames conditions, they are of more significance than many other available data secured at Berlin, Hamburg, Chicago, Columbus and Lawrence, because, as in the case of New York harbor, they deal with tidal estuary waters which contain a substantial proportion of salt and other constituents entering on the incoming tides from the ocean.

Mention is made of the admixture of sea water at this time because of the fact that where anaerobic decomposition takes place in certain small portions of a volume of sewage-polluted sea water, sulphides and sulphureted hydrogen may form through reducing action taking place upon the sulphate of lime with a consequent production of foul odors, and reducing the dissolved oxygen content in a water which on an average might show initially a higher percentage saturation than a similarly polluted land water.

Indeed, if this were a question dealing with the capacity of land water to digest sewage, I should feel disposed towards reducing your proposed standard of 3 cubic centimeters per liter to 1 cubic centimeter per liter. The latter figure is too low to allow of fish life to thrive. Notwithstanding, it is my opinion that a loss of fishing grounds in parts of the harbor which otherwise are kept reasonably clean, both of suspended matter and sewage deposits, is justifiable if such means the saving of many millions of dollars.

I am also aware of the limited evidence available on the amount of oxygen necessary to support salt water fish and that it is not a fair inference to conclude that the oxygen necessary for satisfactory maintenance of fish life for certain land water streams is a criterion for tidal estuaries containing a substantial quantity of sea water.

While dissolved oxygen figures of land waters may indicate conditions differing from those obtaining where the same dissolved oxygen content appears in sea water, still such observations must be given due weight.

In the Royal Commission on Sewage Disposal, Eighth Report, Vol. II, Appendix, page 111, I note the statement to the effect that a fishy smell usually accompanies a condition of deoxygenation equal to a reduction to 3 cubic centimeters of oxygen per liter, which can only obtain in a slow-flowing stream which is polluted with a considerable quantity of effluent or a lesser quantity of sewage. A study of the tabulated field observations, which are presumably the basis of this conclusion, pages 1-15, shows that there is no such condition of fishy smell recorded. Possibly bottled samples tested at the laboratory did show this smell.

In this same volume, page 135, I note a summary of 155 tests for dissolved oxygen in river water classed from "very clean" to "bad." The figures thus summarized do not indicate a more consistent relation between the oxygen content and the water condition as to nuisance than the tables of observations given earlier in this volume, pages 1-51. The range from minimum to average is so wide that it is quite possible that the observations of conditions are based on figures not recorded. Besides, no account is taken of the effect of putrefying sludge deposits, which may be exerting a more objectionable influence than the dissolved oxygen content.

On the other hand, many important observations have been made at Chicago, Columbus, Lawrence, Berlin, Hamburg and other places, showing satisfactory river water conditions to be fully consistent with very low dissolved oxygen content.

I wish finally to emphasize strongly the lessons to be read from the London experiences with the Lower Thames. There, starting some 25 years ago with a noisome river, with oxygen often exhausted during the summer, and with much of the bottom and banks covered with foul sludge deposits, the installation of simple sedimentation methods, aided by a very moderate addition of chemicals, has for 25 years served the purpose and is still sufficient. In spite of the large increase of tributary population during this period and the corresponding increase of organic sewage content, the sludge banks are reduced and the river improved to a satisfactory condition; and this with an oxygen content far below the standard of 3 cubic centimeters per liter the Commission has suggested for the waters of New York harbor.

CORRESPONDENCE CONTAINING MR. FULLER'S ENDORSEMENT OF THE COMMISSION'S RECOMMENDATION FOR THE GRADUAL CONSTRUCTION OF THE LOWER EAST RIVER PROJECT

March 16, 1914.

George W. Fuller, Esq.,
170 Broadway, New York City.

Dear Sir: Since your report of October, 1913, was submitted, some of the opinions and projects relating to sewage disposal, upon which that report was based have been so altered in preparation for this Commission's final report that it seems desirable to bring the changes to your attention and to ask your opinion in regard to them.

The changes made affect the minimum percentage of dissolved oxygen permissible for the water and the Commission's plan for the protection of the Lower East river. These are the only two subjects upon which you were not in substantial accord with the Commission's views when your report was made.

With respect to the oxygen question, this Commission considers that it will not be necessary to include a restriction as to oxygen in the standard of cleanness which should be established as a guide in protecting the harbor against sewage, for if the other provisions of the standard are complied with, there will, in the opinion of the Commission, be sufficient oxygen in the water to answer the requirements.

With respect to the plan for the Lower East river, the Commission expects to recommend that the same principle of gradual construction be adopted in building the main drainage and disposal works which will be necessary for the Lower East river as the Commission has advised in the projects which it has proposed for other parts of the city. Instead of carrying out the ocean island project with its interceptors, siphon, pumping station, main, island and settling basin disposal plant as one undertaking, only the first stages in the execution of this comprehensive plan would be undertaken in the near future.

The works to be taken in hand at first would be, for Manhattan, an intercepting sewer running along the Manhattan water front from the Battery at the south and 26th St. at the north to a point near Broome St., where a screening and pumping station would be located. The screens would operate upon the most efficient principle for fine screens. The sewage, after screening, would be discharged well out from shore at the bottom of the river through multiple outlets.

On the Brooklyn side, the sewage would be collected by an interceptor from Classon Ave. at the south to Newtown Creek at the north to a point near South 8th St., where it would be passed through screens like those on the Manhattan side of the river and pumped through submerged outfalls lying on the river bottom to a distance sufficiently far from shore to insure immediate and thorough diffusion.

The sewage from the rest of the Lower East river territory in Manhattan and Brooklyn would be collected for screening and discharge probably to as many points as there were subdivisions or principal drainage areas. When, after these works are carried out, it is found necessary or desirable to afford further protection to the Lower East river, the city can proceed to construct the siphon to carry the sewage of Lower Manhattan beneath the East river to the Brooklyn shore, where, after joining the sewage from the screening plant at South 8th St., it would be pumped to sea.

In the final development of this plan, it will be necessary to construct the pumping station on the Brooklyn side, the main to the ocean outlet and the island, where the sewage will be treated before final disposition. No part of the original construction will have to be discarded except the submerged outfalls.

The Commission believes that the idea of proceeding in the manner indicated toward the gradual and ultimate construction of the ocean island project may meet with your approval, inasmuch as you consider that it will not be necessary to divert a large amount of sewage from the Lower East river and that screening and discharging the sewage beneath the deep, strong currents of the East river will permanently meet the requirements of the situation. The Commission is of opinion that the ocean island project will be recognized as a necessity before many years and is willing to leave the correctness of its opinion or of your judgment to be determined by experience.

If it never becomes necessary to build the siphon between Manhattan and Brooklyn and carry the sewage to a distant point for disposal, the stage of construction which the Commission is now preparing to recommend and which it is hoped you will approve of can be left as the completed work.

Very sincerely,
(Signed) George A. Soper,
President.

March 17, 1914.

Dr. George A. Soper, President,
Metropolitan Sewerage Commission,
17 Battery Place, New York City.

Dear Sir: I beg to acknowledge receipt of your letter of March 16th.

I understand that your studies of the past few months have led you to make certain changes in your program for the protection of the Lower East river, and that the recommendations that you now propose to make are:

1. That the minimum percentage of dissolved oxygen in the harbor water as one of the specifications of the standard of cleanliness be eliminated.

2. That instead of building the proposed outlet island in the Atlantic ocean in the immediate future, you would have the sewage naturally tributary to the Lower East river collected at certain selected points and there subject it to fine screening and discharge it through submerged outfalls at suitable points in the river bottom.

3. That present construction be adapted to use in connection with the outlet island project, but with the need for the use of the latter project to be investigated and determined after the completion of the works now recommended.

4. That further construction beyond that stated in Paragraph 2 be deferred until the need is determined.

I fully agree that these recommendations are proper ones.

Yours respectfully,
(Signed) George W. Fuller.

SECTION IV

REPORT OF RUDOLPH HERING, C. E., Sc. D.

Metropolitan Sewerage Commission of New York,
Dr. Geo. A. Soper, President, New York City.

Gentlemen: On July 22, 1913, Dr. Geo. A. Soper, President, Metropolitan Sewerage Commission, addressed a letter to me, from which I quote as follows:

> "I am authorized to request you to make a report on the work of the Metropolitan Sewerage Commission of New York. The ground to be covered is the necessity and sufficiency of the plans which the Commission has proposed for the disposal of New York's sewage. It is expected that your study will include an examination of this Commission's reports, and other data, and a consideration of the principles upon which the plans are being prepared.
>
> "Facilities will be afforded you to become familiar with the conditions which exist and which may reasonably be expected in the future, and to understand the opinions and policies which have guided the Metropolitan Sewerage Commission throughout its work."

In accordance with this request I respectfully present the following report:

The Commission has collected during the last few years a vast amount of information, consisting partly of facts obtained by original observations, investigations and compilations, and partly of opinions and experiences obtained from a large number of experts, familiar with the different phases of the problem.

This information forms a storehouse of facts and opinions pertaining to the largest and most complex sewage disposal problem which has yet required a solution.

The Commission has based upon this extensive information general plans for the removal of the present pollution of the harbor and for the disposal of the sewage of the Metropolis extending into a distant future.

I have read your comprehensive reports, have examined some voluminous matter not printed, maps, tables, specimens collected, am familiar with the general conditions as a long-time resident of the Metropolis, and have recently reinspected certain of its localities having the worst polluted waters.

Introductory Remarks

As a preliminary to the discussion which follows, I shall briefly state the main conditions which I consider are the foundation of the problem to be solved.

The Metropolitan community, at present estimated to contain over five million persons, resides upon about 700 square miles of land in the States of New York and New Jersey, bordering the Hudson river, the East river, the Kill van Kull, the Arthur Kill, Newark bay and the Upper and Lower New York bays. The water areas cover together about 200 square miles.

The entire area, now populated and to be populated in the future, drains into these watercourses, whether it is the natural flow from the rainfall washing its surface or the artificial flow of the city sewage and manufacturing waste. New York being the largest shipping harbor in the world, there is added to the discharge of this dirty water or land sewage a large amount of ship sewage, which also contributes to the pollution of the harbor waters.

Although your Commission is confined by law to the consideration of the conditions within the limits of the State of New York, and has therefore excluded a thorough investigation of the conditions within the limits of the State of New Jersey, it must be evident that a political boundary in the middle of a river or a bay, both shores of which are densely populated, does not produce a sanitary boundary, so far as the pollutions of the water and of the stream bed are concerned. You have, therefore, here and there extended some of your observations across the State line, and it is to be regretted that the same thorough examinations as have been made on the New York side could not have been made of the waters and shores of the New Jersey side of the rivers and bays.*

As a thoroughly satisfactory and final solution of the sewage disposal problem of the Metropolitan area must embrace the respective populated areas within both States, and as the solution must apply to their polluted waters, and should accomplish the desired benefit at the expense of both States, rated in fair proportion, the conclusions to be reached at the present time should be drawn with this point of view, and in the following discussions this broader aspect of the question will be kept in mind, so far as practicable.

The direct discharge of all of the filth from rain-water washings and from the city and ship sewages into the waters of the Metropolis has caused at many points of the harbor quite objectionable conditions to sight and smell.

a. One can see floating upon the surface of the water over extended areas of the harbor much excretal matter discharged by the sewers.

b. One can see also the turbid sewage water extending into the river quite a distance from the sewer outlets.

c. Bubbles of gas rising to the water surface at many points, some of which contain malodorous gases, indicate an accumulation of putrefying sewage sludge deposits, chiefly at sewage outfalls near the shores, within the slips and at other points in the harbor.

d. Analysis of the water into which the sewage has entered indicates several changes from the original composition of the water, the most significant of which for the present purpose is the reduction of oxygen, which is usually found to saturate normal and unpolluted waters. The oxygen dissolved in the water acts in a similar manner as the oxygen contained in the air, by converting lifeless unstable organic matter into resistant stable inorganic matter. When organic matter, particularly such as breaks down readily, exhausts the available oxygen, or cannot withdraw it fast enough to form the new inorganic combinations, then other processes of decomposition substitute themselves.

e. In the *presence* of sufficient oxygen the breaking-down process of organic matter is inoffensive. In the *absence* of sufficient oxygen the process can be either offensive or inoffensive. It is offensive when the resulting malodorous gases include chiefly sulphur compounds. It is offensive when the resulting gases are chiefly marsh gas and carbon dioxide and exclude the malodorous gases by processes only quite recently made practicable.

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*This is an error. The Commission's investigations were by law required to cover New Jersey as well as New York, and the existing conditions of sewerage and sewage disposal are fully described in the Commission's Report of April 30, 1910. Ed.

Lifeless organic matter, such as we find in sewage, can therefore be decomposed, so far as odorous results are concerned, by offensive and inoffensive processes. Naturally all efforts to dispose of the Metropolitan sewage should be devoted, as far as practicable to the selection of those processes which are inoffensive.

The present direct discharge of sewage into the waters of the Metropolis at many points not only causes objectionable conditions as to sight and smell, but may also cause disease germs to enter these waters and in several ways cause subsequent injury to health. Let us consider also these objections for a moment.

a. If waters are to be used for drinking there can be no question but that injury could result to the health of the consumer from any sewage discharge as above stated. Such waters should never be used for drinking in their raw state. Nor would such waters necessarily be safe if only the domestic sewage were kept out, still leaving to enter the rain-water washings from the streets of a large city area, the overflow from sewers in times of storm and the ship washings and waste from a harbor. All such street wash, sewer overflows and ship sewage expose the rivers to the reception of pathogenic bacteria and endanger the health of those imbibing the water. As, however, the waters surrounding the New York Metropolis are brackish, the question of use for drinking is, of course, excluded, except when it is accidentally swallowed while bathing.

b. If the water which receives sewage, or even only sewage overflows or street washings, is used for bathing, washing, or if hands should be wet by it, it is possible that some infection might be transmitted. While direct and sufficient evidence hereon is lacking, it is reasonable at all times to keep this point in view and to give it close attention.

c. Pathogenic bacteria contained in sewers, such as cholera vibrios and typhoid bacilli, are not hardy. When floating in water and entirely separated from their nutriment they soon perish. But when imbedded within their nutriment in night soil or sludge they have lived for years. No proof exists, I believe, that if taken into the digestive organs of fish such bacteria have infected the meat which is used by us as food. Abundance of proof exists, however, if typhoid bacilli are drawn within the shells of oysters that they find sufficient nutriment therein to sustain their life and when the oysters are eaten raw they have caused the consumer to contract typhoid fever.

We must therefore face the important facts, on the one hand, that from a large inhabited areas pathogenic bacteria may and do enter the adjoining watercouses, even should the largest portion of the sewage or even all human sewage be kept out of them; and on the other hand, that they may be taken up by fish, and certainly are taken up and nutured by shell-fish in brackish and salt water.

There is no practical and economical way, in my opinion, to prevent all pathogenic bacteria from entering the Metropolitan waters. Irrespective of sewage overflows and ship sewage, the discharge of which it would be difficult if not impossible to control, it is impracticable to entirely exclude the rain water, which washes the streets and yards, in the dust of which are deposited all kinds of bacteria found in a densely populated city. How far it will be economical to proceed is a question not yet definitely determined. It is practicable only to minimize this danger.

To minimize the objectionable effects of rain-water washings and sewer overflows, the most efficient means are:

First, to abolish entirely all intercepting sewers from overflowing into the river.

Second, to permit at suitable and numerous points the first rain-water wash from the streets, which is sometimes as foul and as dangerous as ordinary sewage, to enter into intercepting sewers and mingle with the domestic sewage for equal treatment. The wash of the later period of a rainfall could be left to enter the rivers with much greater assurance that all objectionable matter is excluded than without the prior interception. How far this expedient is practical must, of course, be determined by local studies.

On account of the increasing number of subways in Manhattan extending north and south and interfering with the combined sewers naturally running east and west, it has appeared as though a separate or double system might become economical for this part of the Metropolis. If this should be the case, and if the domestic sewage of Manhattan or a part of it would have to be subjected to some treatment, it might be found practicable to add to this sewage also the first wash from the streets, as collected by the rain-water drains.

If we admit the impracticability, as I do, of establishing a sewage treatment which excludes from the Metropolitan waters positively all pathogenic bacteria, it then becomes necessary to face the alternative requirement, namely, to protect the Metropolitan community against every possible danger from infection through whatever bacteria will still enter the harbor. The following restrictions, therefore, seem to me to be inevitable in the future.

a. Bathing and washing may be prohibited or permitted in the Metropolitan waters only within respective areas, each of which should be officially determined and fixed.

b. No fish or crabs should be placed on sale in the market that have been taken from Metropolitan waters within limits officially determined and fixed.

c. No oysters, clams or mussels for any market should be dredged in Metropolitan waters within limits officially determined and fixed.

To recapitulate, the Metropolitan problem of sewage disposal, therefore, embraces the collection of the sewage in a manner which, so far as practicable, avoids putrefaction within the sewers and is delivered at points where it can be given a final disposal without nuisance of any kind and at any place, and which will prevent, either directly or indirectly, all danger to health.

The collection and delivery of the sewage depends upon the manner in which it is to be disposed of and therefore upon the points where it is to be delivered. The ways in which sewage can be collected and delivered, namely, in sewers with good grades, smooth interior surfaces with no opportunities for a detention of the sewage, are all well known and need no further remarks except that in this respect improvements could be made in the different boroughs at many points. The new problem before the community is therefore substantially confined to that of the

Final Disposition of the Metropolitan Sewage

A final disposition should be made without causing any nuisance or any danger to health. To fulfil the latter condition it was stated above that, on account of not being able to completely prevent all pathogenic bacteria from entering the Metropolitan waters restrictions should be placed upon the use of such waters for bathing and upon the marketing of fish, crabs, oysters, etc., taken from them within limits to be established by law. Similar restrictions exist in the cities of Germany on the Rhine and Elbe and in English cities such as London.

A very material reduction of the dangers to health is brought about by the circumstance that the treatments which will prevent a nuisance, remove also the pathogenic bacteria which may attach to the same, leaving but a very small proportion which may escape death. Therefore, in the studies made by the Commission chief attention was paid to the means of preventing a nuisance.

From preliminary conclusions reached above, sewage purification may be accomplished by ways and means which are offensive and inoffensive and all present efforts are tending to apply processes which belong to the latter class.

Offensive means are those resulting from the absence of oxygen, together with the presence chiefly of sulphur bacteria. So-called septic tanks are the best illustration of the offensive process.

Inoffensive means are those resulting either in the presence of oxygen, or when this is exhausted, in the practical absence of sulphur bacteria. In the following only the inoffensive means will be discussed.

A. DECOMPOSITION BY OXIDATION

Dead organic matter varies from being very resistant to being non-resistant to decomposition. In other words, it may vary from being stable, as bones or hardwood, to being very unstable, as blood or vegetable juices. The resistant condition allows of a very slow decomposition and does not concern us here, because a nuisance does not arise thereby. The non-resistant condition rapidly changes the constitution of the matter, either inorganically or by the action of bacteria, which seize upon the oxygen in contact with it and form new combinations through oxidation.

Therefore, the exposure of unstable dead organic matter to a contact with oxygen in sufficient quantity and for a sufficiently long time, effects an inoffensive decomposition which can be obtained either in air or in water, and at temperatures suitable for bacterial activity.

Oxidation in the air, *i. e.,* on land, is obtained when the sewage is spread out as a thin film upon a firm substance, exposing to the air as much surface as practicable. We have then the most favorable relation between the exposed area of surface, the quantity of air available, the best conditions for bacterial activity and the degree of purification accomplished. Percolation through beds of sand and beds of coarse-grained materials are the best practical means of securing a favorable relation for oxidation on land, as is well known.

When the sewage is diluted in a body of water its oxidation is obtained by a thorough exposure of the dissolved and finely suspended matter to the oxygen dissolved in the water. Thorough dispersion in a sufficient quantity of flowing water is therefore the practical way of securing it.

As the quantity of dissolved oxygen available in the water, when compared with the quantity available in air, is not as large, oxidation in water is not as rapid as oxidation on land, nor can the same result be accomplished with the same cubical content of medium as on land. On the other hand, oxidation in water is much more economical, because it does not require extensive special works nor as much labor, and an immediate dilution in sufficiently oxygenized water at once stops the generation of odor.

In order to secure the desired oxidation most efficiently, both on land and in water, it is customary to limit the character of the sewage thus to be treated to the dissolved and fine suspended matter. The coarse suspended matter is therefore generally first removed from the sewage.

The practicable means for securing the oxidation of liquid sewage by filtration on land are so well known that for given requirements and conditions of the New York Metropolis, the necessary areas, capacities and costs may be readily ascertained. We are less certain regarding the best means of separating the coarse floating and heavy matters from the dissolved and fine suspended matters and of detaining and separately treating them. The latter subject therefore requires a few remarks.

Three practicable means exist and are used to obtain such separation. One is a detention by screening, another by floatage and a third by deposition.

Screening is limited to the detention of suspended and floating matter, the particles of which are larger than the openings in the screen. These openings vary from 6 inches, holding back only very bulky matter, to very fine slots, the finest being those of the screen bearing the name of the inventor Riensch, where the slots are but one millimeter wide. Without elaborating this subject we can simply conclude from the experiences gained, chiefly in Europe, that fine screening can satisfactorily detain most of the suspended and floating matter objectionable to the eye.

Screening with Riensch screens is the only treatment given in Dresden. Screens are sufficient also in Harrisburg, where they have openings of one centimeter. Still wider openings are satisfactorily used in screens in England, where the sewage discharges into estuaries.

In quite a number of European cities screening is the only treatment given the sewage discharged into watercourses. In others it is used as a means of preliminary treatment followed by some process of oxidation.

We are not yet agreed upon the best general devices for screening, nor upon details of the apparatus. In my opinion it would be best to take by itself each case in the Metropolis where screens are to be used and from among the several well-tested devices known select for it the one which will accomplish what is desired at the least cost. The heavy storm-water flow in our combined sewers and the rise and fall of the tide increase the difficulties.

In all cases of screening, even where the finest screens are used, there is still discharged with the sewage a large amount of fine suspended matter. The amount is usually greater in weight than that which is detained by the screens. The passing sewage contains also the larger portion of the non-resistant organic matter. This fine matter may be carried in suspension until it is deposited as sludge, either on the bottom or at the shores of the stream. It is gradually dissolved and decomposed either while suspended in the water or after deposit as sludge, which process will be referred to later.

The screenings themselves are removed periodically by hand or continuously by machine and are treated more or less successfully in various ways according to local conditions. A removal of the moisture by pressure to reduce the bulk for handling, with a subsequent burial or incineration, is the most usual treatment given. If the screenings are promptly thus disposed of when fresh no nuisance need result.

Another means of securing a separation of the solids from the liquids is by facilitating the *floatage* of light matter.

When the velocity of a moving liquid is reduced or ceases suspended matter lighter than water rises to the surface and if prevented from passing on, as by scum boards and end walls, it will accumulate on the surface and can be periodically removed in bulk by hand, or continuously by machine, as in the case of screens.

Floatage collects the light suspended matter by passing the sewage through tanks or detention chambers, of larger section than the sewer, to reduce the average velocity to, say, about 3 or 4 inches per second, and by providing a submerged outlet at the bottom, the discharge pipe from which leads into the river.

Floating matter is thus detained at the surface and includes also some fine suspended matter not detained by screens, the amount depending, of course, upon the velocity with which the sewage passes through the detention chamber. Matter not rising to the surface will not be retained, but will enter the river.*

In order to prevent any deposit of heavy matter in the outfall pipe, a grit chamber is placed ahead of the detention chamber, causing a velocity of not much over nor much less than 12 inches per second.

In case of a combined system, the chamber should be placed to one side of the sewer, so as to allow the storm-water flow to pass as before to the river, and by self-acting float valves be prevented from entering the chamber. The water level and floating matter in the chamber rises and falls with the tide. The floating matter can be disposed of by burial or burning.

A third means of securing separation of solids from the liquid matter is through their detention by *deposition* in settling tanks or chambers. These tanks allow the heavier materials to deposit, the floating matter to be retained and the liquids and non-settling fine suspended matter to pass on.

As the velocity of flowing water decreases matter held in suspension by its movement begins to deposit. The well-known curves, showing the relation of velocity and subsidence of sewage matter give us the means of estimating the percentage of suspended matter which can be removed by subsidence during given time periods of detention.

The mean velocity of the sewage passing through such tanks has varied from ½ to 2 inches per second. Experience has established the fact for European sewage that a period of detention of one to two hours causes a deposit of all matter which it is found economical to remove by this means and to be treated separately. The remaining suspended matter is very fine and it is found that practically all of it can be taken care of with the liquid sewage by subsequent oxidation.

In settling tanks it is natural to collect also the floating matter, as the velocity in them is small, and even more floating matter than in the former case can be collected. Settling tanks must be much larger and are therefore more expensive than chambers designed to retain only floating matter.

If sewage is delivered to the point of deposition in a fresh condition, which can readily be done by sewers, even several miles in length when these are properly built and kept clean, when the sewage is detained not longer than two hours to deposit its suspended matter, and has its floating matter properly removed, no offensive conditions will result, if reasonable care is given the works.

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*The term "floatage" is probably original with the author. It does not appear that works have anywhere been built thus far to carry out the object here mentioned. Ed.

B. DECOMPOSITION IN THE ABSENCE OF SULPHUR BACTERIA

When sewage is examined quite fresh from the points of origin, as in a clean house drain, very little organic matter is found in solution. When strained through filter paper and left standing it rarely becomes foul. As the sewage continues to flow in the sewers more and more matter is dissolved and at the outfalls in many cities we find about one-half of the organic matter to be in solution.

With the increasing quantity in solution bacterial activity also increases and consumes the oxygen present in the sewage much faster than it can be reabsorbed from the air. Eventually, unless prevented, the oxygen is all consumed and putrefaction begins.

It would therefore be desirable, where it is practicable, to begin treatment by an early separation of the solids from the liquid matter and in any case well before the oxygen dissolved in the liquid has been exhausted.

The treatment, so far as described above, is first a separation of the bulk of the solids, either by screening, floatage or sedimentation. We must now secondly consider the treatment of the solid material which has been deposited in settling chambers or tanks, and which is called sludge.

Until within a few years the treatment of domestic sewage sludge invariably caused an offensive decomposition in the presence of sulphur bacteria when collected in plain sedimentation or septic tanks. It is now practicable to effect the deposition and a subsequent more rapid decomposition in a more satisfactory manner without any offensiveness; and only such processes should here be considered.

As non-resistant sewage sludge withdraws oxygen from the water more rapidly than it can be replenished from the air it may soon become exhausted. The conditions of decomposition then change and new classes of bacteria become active. The aerobic bacteria cease to work and the anaerobic bacteria develop as their successors.

Under the ordinary conditions when oxygen is exhausted we find that some of the anaerobic bacteria produce sulphureted hydrogen and occasionally other foul gases. Septic tanks, privy vaults, unclean sewers with deposit, extensive sewage deposits in rivers and harbors are always instances of foul decomposition, because of the lack of sufficient oxygen for the oxidation of the non-resistant organic matter present.

It has lately been discovered that under certain simple conditions it is possible to eliminate the bacteria which develop sulphureted hydrogen and to restrict the anaerobic bacteria to those producing chiefly marsh gas and carbon dioxide, neither of which gases is offensive.

That this result can be secured under all ordinary conditions is now abundantly proven in practice by the successfully inoffensive sludge decomposition in over 130 plants, most of which are in Germany. The plants operate equally well under a variety of conditions, dilute and strong domestic sewages and trade sewages from metal, acid and alkali works.

The essential features of the process to secure this result and as developed by Dr. K. Imhoff are as follows:

The sewage moves through a chamber in which it is detained from 1 to 2 hours. During this time from 90 per cent. to 100 per cent. of the settleable suspended matter deposits upon an inclined bottom and slips through a slot into a chamber below. The slot is so arranged that no gas bubbles resulting from decomposition and no sludge particles or water currents can rise from the lower into the upper chamber, to mingle with the fresh sewage, but instead they rise through a special shaft directly to the air.

The decomposition of the accumulated sludge in the lower chamber gradually assumes and then maintains a condition in which the classes of anaerobic bacteria-producing offensive gases are substantially eliminated and only those remain which produce about 75 per cent. of marsh gas and 25 per cent. of carbon dioxide.

After the sludge decomposition in the lower chamber has become fully established there is not only an absence of odor from the escaping gases at the surface or from the shafts, but also an absence of odor of the sludge itself, both while it is decomposing and after the process is complete. The absence of bacteria-producing foul smelling gases is therefore evident.

When the sludge has been in the lower chamber some 3 to 6 months, depending chiefly upon the character of the sludge and the temperature, and has been kept in condition favorable to its decomposition, it can be withdrawn without emitting offensive odor, as the non-resistant matter has all been eliminated by the decomposition.

This new sludge differs from the usual sludge, and especially from that of septic tanks, by its absence of offensive odor, by its friability, due to the absence of non-resistant slimy and sticky matter and by its porosity, due to the expansion of the gases of decomposition while the sludge rises from the bottom of the lower tank to the surface of the ground. These qualities allow the sludge to be spread out over sub-drained areas and dried ready for removal in about a week. It then resembles garden soil.

Where sufficient area for this drying is not available, the sludge can be withdrawn from the tanks and removed either on land or water to points of final disposition.

Where the means of removing the sludge from the sewage by sedimentation is impracticable for local reason, there is left only one other means, namely, letting the sedimentation take place as at present, in the river near the outlet of the sewer. This means is also least good because of the tendency as at present to deteriorate the harbor water.

In this case the sludge must be removed directly from the river bottom, as frequently as practicable, by a suction dredge placed at the fore end of a barge, with or without a diver handling the nozzle.

For the removal of the sludge it is questionable whether it will be cheaper to have barges sufficient in number and large enough to hold and remove also the large percentage of water which is brought up with the sludge or to separate most of the water from the sludge by a centrifuge and discharge it through a separate hose hanging down to within a few feet of the river bottom from the rear end of the barge. It would be necessary to discharge this water near the bottom on account of its being offensive. The frequency of such a removal will depend upon the effect which the deposited sludge has upon the harbor water. The interval between the removals should not be long enough to allow effervescence to occur.

When the sewage is allowed to pass from a sewer directly into the river a screen must, of course, always be provided, and also a grit chamber if it is found necessary.

New York Harbor Conditions

1. *Investigations Made by the New York Metropolitan Sewerage Commission.*

The Commission has made a very extensive and systematic study of the New York harbor conditions. It has collected more data on the physical and social conditions than have probably been collected for any other harbor.

The Metropolitan area investigated is over 700 square miles. A large number of maps have been prepared indicating almost every phase of the problem. Thousands of bacterial and chemical analyses have been made of the waters at all depths, at all seasons and at practically all important points. Over 100 experiments were made with floating objects, to show the movement of the main tidal currents, indicating their oscillation and the slowness with which the polluted harbor water gets out to sea. Besides these investigations innumerable others were made leading up to the designs that have been proposed. The studies included almost every solution of the problem that might be suggested, also some which were soon eliminated for reasons given.

The general conclusion reached is that the sewage disposal in the Metropolis should be radically improved in several directions, and the suggested improvements have been outlined in the reports.

2. *Currents and Tides.*

The Commission, in connection with the U. S. Coast and Geodetic Survey, has studied the currents and tides, the former in more detail than has been done before. It found, as one would expect, that there is no more water flowing seaward (tide oscillation excluded) than the land water which enters the harbor, and that a large part of the harbor water goes into the Lower bay and the sound with every ebb tide. The sea water returning into the harbor at flood tide at the Narrows and Throgg's Neck was found to be not entirely free from oxidizable sewage matter.

The Commission further found that water of the East river between the Upper bay and Throgg's Neck simply oscillates within this stretch most of the time, and that the diluting water is received at both ends.

The rising and falling of the tide averages about 4.4 feet at Governors Island. Tidal and land water have different limitations in quantity of discharge. As regards their ability to flush out the harbor it can be said that tidal flushing is capable of keeping a number of the channels free from deposit and sludge, as, for instance, a large part of the East river. Land water flushing can apply to the Hudson river only when this is in flood. In floods much of the deposited and partly decomposed organic matter may be picked up by the increased velocity of the water and carried into the Lower bay and to the bar. On the other hand, when the flood recedes much of the partly decomposed matter brought down is deposited with the Metropolitan sewage in the bay. Therefore I do not consider that floods in the Hudson river, so far as sludge removal is concerned, have a very beneficial effect, except by temporarily cleaning the river bed in some locations and redepositing sludge in others, and by bringing into the bay fresh water having a high percentage of oxygen, soon to be lowered, however, to the present figures.

3. *Sewage Discharge.*

All of the Metropolitan sewage with little exception is turned into the Metropolitan tidal waters. Besides the floating fecal matter, of which about 625 tons are discharged into the harbor every day, making the surface of some of these waters unsightly and objectionable, bacteria can be found in the water almost everywhere, and about 16 tons of sludge are said to be deposited in the harbor daily.

To fully appreciate the relation of sewage as discharged into rivers to its effect upon the river water, we should not lose sight of the deception likely to be introduced by the designation of sewage discharge as a quantity of water per capita, the quantity of water depending entirely upon the water supply and sub-soil leakage and holding no relation to amount of pollution.

What we are interested in is the organic solid and liquid sewage matter per capita in solution and in suspension, which is a fairly well fixed quantity. The water supply gives this sewage matter its first dilution. Sewage of American cities is two and three times as dilute as the sewage of European cities, but we have no more sewage matter per capita to purify than they have. When our sewage is discharged into a river it is already much more diluted than European sewage. When in Europe they require 30 dilutions to satisfy the demands for an inoffensive river disposal, we in this country would have to require only about 10 to 15 dilutions, other things equal, to accomplish the same result.

The numerous and comprehensive bacterial analyses made by the Commission serve as a good index of the conditions of the water in the harbor.

Noteworthy are the general facts that the largest number of bacteria are near the surface, and, with very few exceptions, the smallest number is near the bottom, because the oxygen coming from the air is most readily available at the top. And again, sewage sludge has many times the largest number of bacteria, although mostly of a different kind, because of the greater quantity of decomposable matter present. The greater bacterial activity in the water at the surface than near the bottom perhaps explains the fact that the dissolved oxygen is occasionally found to be slightly less at the top than near the bottom.

The greater the number of bacteria the greater is the pollution by dead organic matter, and at the same time the greater is the effort of nature to mineralize this objectionable matter. Generally, therefore, we should welcome a high bacterial content in water as beneficial, where we cannot prevent the presence of dead organic matter in the water.

Intestinal bacteria are abundant in the harbor, but only a few kinds are pathogenic. Pathogenic bacteria are, of course, very objectionable, but fortunately, when entirely out of their element, they soon perish. There is a risk, as already stated elsewhere in this report, when pathogenic bacteria get into oysters or when bathing or handling driftwood permits their entrance directly or indirectly into the mouth.

The water north of the Narrows is, in my opinion, unsuitable for the cultivation of shell-fish at any point. It may possibly also be dangerous to bathe in, and the collection of driftwood fuel may be attended by some risk of contracting disease.

For the further purpose of this discussion let us again consider the sewage of the Metropolis in its three parts: That which floats, that which settles and deposits and that which remains in suspension or in solution and is carried along with the flowing water. The first two parts will be mentioned presently and the last one now.*

The Commission has obtained information regarding the relation of the incoming salt water to the outgoing fresh water and their mixture, and regarding the increase of salt water and therefore of the increase of coagulation and precipitation of the organic matter. It is also known that plankton perishes and deposits to a larger extent in brackish than in either fresh or salt waters.

We may conclude from these and other facts that in New York harbor as in other tidal streams there is a greater tendency than in land water streams to precipitate and deposit solid matter. The shoaling of all coastal streams in their tidal reaches is a well-known fact.

A second matter of importance is the tendency of the liquid and fine suspended matter of sewage to become thoroughly dispersed through the river or harbor sections.

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*This division of the question, and in fact much of this part of the report has been already discussed in the Reports of the Commission. Ed.

You say (Report, August, 1912, page 27), particularly with reference to the East river: "The configuration of the shore line and bottoms and the velocity of the tidal currents all combine to bring about a thorough intermixture of the water." And again (page 34): "It appears that the liquid portion of the sewage which is now discharged into the harbor becomes thoroughly commingled with the water soon after it loses its identity as sewage. After it has once become mixed with a few times its bulk it becomes difficult to recognize it by sight. Marked stratification usually does not long persist."

And again (page 32): "The sewage which is discharged into the waters of the Lower East river is soon diffused. Except where piers and slips interfere with the normal tidal action, the mixing effect of the rapidly moving currents is clearly apparent." To indicate the occasional diffusion of the Hudson river water throughout the harbor water as indicated by its turbidity, you further say: "At times of heavy rain the influence of the Hudson can be detected by the turbidity which it produces through the Upper and Lower bays, Kill van Kull and the East and Harlem rivers."

You also say: "The presence of minute particles of suspended matter well distributed through the volume of the main tidal currents is in itself the least objectionable feature connected with the disposal of sewage by diffusion."

The percentage of dissolved oxygen is fairly uniform throughout the cross-sections where the current is fairly swift. It drops down near the shores where sewers discharge, showing that its effect is probably soon felt. The sewage matters in the harbor water are not all in the fresh state, but in various stages of decomposition, from the early carbon fermentation to the late stages of nitrogen fermentation.

From this evidence we may conclude, if sewage is discharged into the current instead of at the shore that its dispersion throughout the mass of moving water is greatly improved, and you have therefore suggested that such means of dispersion should be artificially created at as many points as practicable.

Regarding the detail of such means of dispersion, the discharge pipes should extend laterally across the current, outlets should be small and numerous and direct the issuing stream as nearly horizontal as practicable, so that the dispersion will be more rapid and complete than otherwise.

Where the sewage must be discharged at the pier head, the outlet should be placed as far below the low tide level as practicable, so that the liquid will get some dispersion before it reaches the surface, if it reaches it at all. The designs of the Commission have been made with consideration of these practices.

4. *Floating Matter.*

The suspended sewage matter which is lighter than, and therefore floats on the surface of, the harbor water, is in my opinion the most objectionable aspect of the Metropolitan sewage question at the present time.

It was apparent as a nuisance 25 years ago and as such it has since been materially increased instead of reduced. In fact, I consider it to have been the chief cause for the recent popular agitation for better sewage disposal in the Metropolis. With the floating matter eliminated most of the present offensive conditions of the harbor, with a few exceptions, will have disappeared.

Besides the 625 tons of fecal matter, most of which floats about for a while in large and small pieces, there is also much vegetable matter, some wood and, at several points, also some discoloring trade waste to defile the harbor surface.

Quite a lot of the floating débris in the harbor comes from the docks and from ships, which an enforcement of present or amended ordinances should eliminate.

Other floating material is oil and grease. Unless the quantity is large there is no offensive odor and no unhealthfulness therefrom. When large in quantity it is always an objectionable trade waste and should be excluded from the public sewers and the harbor.

The odor of waste oil, particularly from gas works, sometimes is more offensive than that of fresh domestic sewage. Such waste should also be excluded from sewers and from rivers and from harbors, as is now frequently done in Europe. When the oily film or sleek is confined solely to that which naturally comes from domestic sewage it is very slight in quantity and not offensive to smell, and therefore is not objectionable.

Turbidity of the river and harbor waters is not unhealthful nor does it necessarily constitute a nuisance. Most of it is caused by heavy rains washing the soil of the drainage areas, and it is not practicable to prevent it. Nearly all of our southern rivers are almost continuously turbid.*

To prevent the objectionable floating matter due to private industries and shipping from defiling the harbor we must seek the remedy first at the sewers and secondly by carrying out the police regulations against harbor pollution.

At the sewers we can operate screens, settling tanks or floatage chambers, as may be found most efficient at the specific locality. All such structures require careful design, but also, what is still more important, efficient, frequent and faithful attendance, if their purpose is to be fulfilled. They are frequently used in Europe.

The drifting of floating matter suggested the systematic use of suitable floats to indicate the points to which sewage would flow and do harm. When in 1882 a large series of float determinations had been made in Providence bay, Rhode Island, I found that this method was very deceptive for such a purpose, except as relating to large and plainly visible floating matter. It does not take account of the diluted, dissolved or dispersed sewage, which may not be recognized at all as sewage when it reaches a shore, at the point where the special float had landed. Nor do such floats take account of the depositing sludge. Only floats used to determine currents give reliable information. Balls placed at submerged outfalls may also lead to wrong conclusions regarding the effect of sewage discharge.

Practical and economical means, to more or less prevent the nuisance resulting from large quantities of floating matter in the harbor, have been in use for many years in other places. In my opinion the Commission cannot too strongly emphasize the recommendations they may deem proper to make for the immediate adoption of means to prevent floating sewage matter from appearing anywhere upon the surface of the harbor.

5. *Sludge.*

The suspended sewage matter heavier than water, and therefore settling in it, is the next most objectionable part of fresh raw sewage discharged in the harbor, because it continuously accumulates, and by doing so withdraws oxygen as rapidly as conditions will permit. After the oxygen available for withdrawal has become deficient in quantity, putrefactive processes are started in the sludge, gas bubbles rise to the surface and carry up with them particles of a putrescent sludge to further deplete the quantity of dissolved oxygen which is being reabsorbed by the water.

One of these gases is sulphureted hydrogen, and having a very offensive odor is, as we know, the principal cause of the present nuisance objected to in the slips and docks of the harbor.

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*The Commission makes a distinction between turbidity produced from the washings of alluvial land and that which is due to excessive sewage pollution. Ed.

Sludge deposits are abundant near sewer outfalls in the slips and docks. The worst nuisances are from Wallabout and Newtown creeks, in the Harlem river and in and from Gowanus canal, because in all these cases the velocity of the water is too slight to carry all of the suspended matter away. The velocities are less on the shallow than on the deep areas, and therefore we find more sludge deposits on the shoals than in the channels of the harbor. The Commission has found: "That practically the whole of the Upper New York bay and the Lower Hudson are underlaid by an accumulation of foul-smelling black ooze."

The sludge deposit in the harbor is not all of Metropolitan sewage origin. In fact, I believe only a small part of it was ever the highly putrescible part of domestic sewage, which is the first to be oxidized by the water. As before stated, much organic matter, chiefly the more resistant part, is brought down the Hudson and deposited in the bays. It originated by the discharge into the river of the rain-water washings from the entire drainage area, including that of the Metropolis. Some of the sludge is also due to the accumulation of dead plankton in the brackish waters. The non-resistant or putrescible matter in sewage has practically disappeared by oxidation. The harbor's sludge as a rule is not very non-resistant, except near the sewer outfalls and in the docks. Some distance away from them, but not near shallow shores, it is in the last stages of decomposition, and no more putrefaction is noticeable by the appearance of any effervescence at the surface, although, of course, some oxygen absorption is still taking place. Near the sewer outfalls there is a good deal of non-resistant sludge deposited, the bacterial activity in decomposing it and the resulting oxygen absorption is much greater and putrefaction is the usual final result.*

The effects from putrefying matter are much more objectionable in the water than are the effects from decomposing fresh matter. The former not only imparts an offensive odor, but the sulphides formed by the putrefactive process have great avidity for oxygen, and by direct chemical action withdraw it from the water, thus assisting its deoxidation with corresponding rapidity.

The recent Manhattan practice of extending the sewers to the pier heads, instead of letting them discharge into the docks, has improved conditions very greatly, but the rising tide still takes some of the suspended sewage particles back into the docks and therefore still causes some deposit due to the slight velocity of the water in them.

The thicker the sludge deposit the less active is its decomposition. Where the deposits have accumulated to depths of over 3 feet the Commission found that below this depth decomposition practically ceases, partly because only matter remained that had been rotted out and partly because the bacteria perish in the seclusion by the poisonous effect of their own products.

A more thorough removal of the sewage sludge than heretofore attempted from the rivers and bays, both at present and hereafter, will, in my opinion, very effectively better the harbor conditions, not only by preventing its putrefaction in the river, but also by increasing the dissolved oxygen content of the water and therefore improving its appearance both in color and clearness.

Dr. Adeney has reported to you (page 100 and page 116 of his report†), and I strongly support his opinion from extended observations both in Europe and America, that: "There can be no doubt that the waters of New York harbor are being injuriously affected by the sewage solids which are being deposited over the greater portion of its bed." "Of all the constituents of sewage the solid matters in suspension cause the most injurious results in tidal waters." "It is the easily and directly oxidizable substances from the foul deposits that now cover the greater portion of the bed of the harbor which cause the large deficiency in dissolved oxygen which have been shown to obtain in the waters of the harbor by the investigation of the Metropolitan Commission."

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*This is in error: Many thousand cubic yards of putrefying sludge were removed by the United States Government engineers in improving Ambrose channel, in lower New York bay, between two and three miles from shore and seven miles from any large sewer. See also this Commission's Report of April 30, 1910. Ed.

†See Report of this Commission of April 30, 1910. Ed.

Opinions have been expressed that the sludge has a less important effect in deoxygenizing water than that imputed by Dr. Adeney. Relevant experiments have been recently made and a verification of his position obtained by the Commission.

In my opinion every effort should be made to keep as much sewage sludge as practicable from depositing in the rivers and harbor by its retention on shore. I believe that at least the worst half of it can be so retained in tanks, and that in addition a good deal can be removed by suction dredges, as already suggested.

When tanks are used it may be found that in some locations—later, if not now—chemical precipitation or rapid filtration may be advisable to increase the retention of more of the suspended matter than will deposit in plain settling basins.

When final detailed plans are made the special character of works for the most efficient sludge removal, whether Imhoff tanks, plain settling tanks or suction dredges, should be determined as to the preference, the cost, etc., for every outfall, as well as the best method of finally disposing of the sludge thus collected.

I do not see why sewage sludge, either at the shores or in the rivers, being objectionable at least as a nuisance, should not be collected, removed and if necessary treated for similar reasons to those which cause us to collect, remove and sometimes also treat the solid refuse of city streets. Sewage sludge may become quite as objectionable as does night soil and old garbage, and to let it putrefy on the bed of a river is a relic of olden times when neither knowledge existed as to how to deal with such matters nor money was available to pay the cost. Keeping the river beds clean in front of our cities is, in my opinion, just as desirable as keeping our streets clean. On the latter we see the dirt, on the river bed we do not see but smell the effects of the sludge. Sludge exists abundantly in our harbors and it affects the oxygen of the water flowing over it in a more destructive manner than the street dirt affects the oxygen of the city air.

I believe that in every civilized community it will not be long before "river cleaning" will be deemed as desirable as "street cleaning."

6. *Dissolved Oxygen.*

The best practical measure of the degree of pollution of any water, to determine the amounts of unstable dead organic matter which it can digest without causing a nuisance and the amounts which probably will cause a nuisance, is the quantity of free oxygen dissolved in the water. Extensive dissolved oxygen determinations have, therefore, been made by your Commission for three years, covering the entire water territory which is concerned in the present case. With this information you have studied the digestive capacity of the harbor and have concluded that: "It will not be necessary to keep all the sewage out of the harbor, for these waters can absorb a large amount of sewage harmlessly and inoffensively. The Commission considers that this capacity should be fully utilized and has undertaken to determine to what extent and in what ways this can be done."

The Commission has carefully studied the effects of sewage discharge into the harbor as indicated by its dissolved oxygen. All the observations have shown a tendency for the dissolved oxygen to become more concentrated near the surface than below, even when a partial depletion exists below. Downward streaming and evaporation indicate the manner in which oxygen is replenished in the water below the surface until it reaches the sludge at the bottom.

Downward streaming is caused by the greater weight of the air-saturated surface water, which may finally reach the bottom, and seems to be the chief means of reoxidizing the layers below. Evaporation in sea or brackish water, due to the solution of sodium chloride and other salts becoming more concentrated, and therefore heavier near the surface, also causes downward vertical currents.

Water flowing in an irregular channel, with changing shores and river bottom frequently changes its course, both vertically and horizontally, and therefore becomes more or less thoroughly mixed. This condition exists to a large extent in the New York harbor, and particularly in the East river, as the Commission has shown.

The result of this constant intermixture is advantageous also in the fact that it facilitates a greater oxygen absorption at the surface. As a rule there is not a great difference between the resulting amount of oxygen in the surface and in the bottom layers, probably because of the greater bacterial activity near the surface.

The depletion of oxygen has taken place pretty generally throughout the entire harbor, but to different degrees in different parts, as shown by your plottings. This depletion has been caused partly by the dissolved and light suspended organic matter which enters the harbor chiefly from the sewers and partly by the deposits of sludge. Where the sewage discharge and sludge deposits are greatest the dissolved oxygen is lowest.

The East river is the most depleted part of the harbor, it receives the largest amount of sewage and has the least favorable opportunity of having its water thoroughly changed and replaced by oxygen-saturated water.

At Pier 10 and at the Brooklyn Bridge the degree of saturation in July and August, 1913, when it was lowest, fell to figures varying from 13 to 25 per cent. Elsewhere the figures are materially higher.

In general it may again be said that sewage cannot be as rapidly purified in water as in air, because of the comparatively small amount of oxygen that is dissolved in water, and because of the less good opportunity there is for contact between sewage matter and oxygen, as compared with filters. Consequently oxidation in water requires a longer time.

As regards the effect of a depletion of oxygen in the water upon fish life, it may be said that for major fish the figure 70 per cent. has been recommended for New York harbor. While it is desirable to keep water for major fish life as highly aerated as possible, we know that such fish have not always been destroyed even by a very much lower figure. In the Potomac below Washington there is good fishing with oxygen occasionally at 50 per cent. saturation. The amount of oxygen to be maintained in water is mainly a question of preference between the financial value of the fish, which may not be able to live in waters used for sewage oxidation and the cost of preventing the deoxidation.

If it were desirable to permit fish to ascend a large stream for spawning, as, for instance, the Hudson, it would not be necessary, in my opinion, to require sufficient oxygen in all of the rest of the harbor water, but only in those waters directly connecting the Hudson with the ocean. It would not be necessary throughout the East river, as the fish in the sound might go elsewhere than up the Hudson for spawning.

Dunbar says: "It is the sulphur forming foul-smelling sulphureted hydrogen which is strongly poisonous to fish life." The result of putrefaction is more injurious to fish life than, within limits, a mere scarcity of oxygen. Therefore, by preventing the putrefaction of sludge deposits and the consequent escape into the water of foul gases resulting therefrom, by the interception of sludge on land, or by frequently removing it with suction dredges from the river bottom, putrefaction can be minimized and the degree of dissolved oxygen increased in the harbor water for the benefit of fish life.

It is my opinion that the question of major fish life in New York harbor should not take the first place in a consideration involving so large an expenditure as would be necessary for the final disposal of the Metropolitan sewage. However, so far as the degree of dissolved oxygen affects the health of the population and affects the question of a possible nuisance to this population, it must be seriously taken into account. I shall refer to this subject again later.

The source of the dissolved oxygen is river and harbor waters is the atmosphere from which it is absorbed. The harbor waters receive oxygen from the Hudson, the Passaic (in the future) and the Hackensack rivers, from the flood tides entering the harbor at Throgg's Neck and at the Narrows and from absorption at the surface of the harbor waters. We may call the area of the harbor waters about 60 square miles.

Practically all of the Metropolitan sewage is now discharged into the harbor, and it also practically disappears within its area. The disappearance is brought about partly by subsidence and decomposition of the resulting sludge and partly by oxidation of the liquid and fine suspended sewage within the harbor.

Ebb tide takes some of the unoxidized sewage out to sea beyond Throgg's Neck and the Narrows. Most of the flood tide, however, brings back almost completely oxygenated water.

If the surface of the water is kept fairly well broken the reaeration readily proceeds. When the quantity of dissolved oxygen is insufficient to oxidize the sewage, the sewage and sludge together may in an extreme case produce black, putrid and foul-smelling water, with bubbles of odorous gases arising from the sludge.

Sludge draws oxygen from the water with greater avidity than sewage in solution, but dissolved matter, on the other hand, decomposes in the presence of sufficient oxygen far more rapidly. The reaeration of sea water proceeds more rapidly than the reaeration of land water. The favorable configuration of the harbor, of land and sea water entrances aiding the intermingling of the waters by the tides and currents, the oscillation due to the tides and the effect of the shipping and winds all contribute to getting a good mixture of sea and land water and of the top and bottom waters, the result of which is shown in the fairly uniform distribution of the dissolved oxygen in most parts of the harbor.

We have various estimates as to the amount of dissolved oxygen necessary to oxidize the screened and settled sewage per second per capita, such as 0.80 mg. in Chicago, 0.35 mg. in Hamburg and 0.22 mg. in Frankfort, etc.

If we roughly assume the figure for New York at 0.50 mg. per capita per second we would require for a population of, say 6,000,000 people, as much as 3,000 grams of oxygen per second, or 260,000,000 grams per day.

Dibdin concludes from some of his observations that all the organic matter in sewage will be completely oxidized by from one to three times its weight of oxygen. The total organic and volatile matter in sewage, averaged from several authors, is about 77 grams per capita per day. We should, therefore, require, according to Dibdin, for 6,000,000 persons from 462,000,000 to 1,386,000,000 grams per day to oxidize the sewage.

If we realize that Dibdin's figures are for getting complete oxidized organic matter from crude sewage and the others are for getting non-putrescible matter from settled or screened sewage, removing a large part of the solid matter, they will reasonably compare with those above assumed. More definite information on this subject is necessary and will no doubt be forthcoming in the future. I understand that the Commission has obtained some.

The oxygen required is partly absorbed from the air at the surface of the harbor and partly brought into the harbor with the flow of the Hudson and with the flood tides from the sound and the ocean. The other sources are negligible.

The ordinary minimum flow of the Hudson river is 1,500,000,000 gallons per day. Let us assume that about one-third of its dissolved oxygen is available for the oxidation of the Metropolitan sewage, say 3 milligrams per liter, or 12 milligrams per gallon. Then the daily amount of dissolved oxygen available from the Hudson river is 18,000 kilograms. The aerated tidal waters entering New York bay twice a day from the ocean and the sound, let us assume to be roughly 200,000,000,000 gallons per day, and let us further assume that the available amount of oxygen in it for oxidizing the Metropolitan sewage is only 5 milligrams per gallon. The daily amount of oxygen available from the ocean waters may, therefore, be 1,000,000 kilograms.

The surface of the harbor, where practically all of the sewage is discharged, namely, about 60 square miles, equals say 1,672,000,000 square feet. If we take Adeney's figures of oxygen absorption of half sea to half land water at 0.055 c.c. per liter per hour, equaling 0.000078 gram per liter per hour, and assume that atmospheric oxygen penetrates the fairly rough harbor surface about one inch in one hour—a safe minimum—then 0.000175 gram would be absorbed per hour per square foot, or 292,700 grams per hour from the entire harbor surface, or about 7,000 kilograms per day.

We may then estimate the available oxygen for sewage oxidation in the New York harbor water quite roughly as follows:

Hudson river..............................	18,000	kilograms per day
Sea water..................................	1,200,000	" " "
In the Bay and East river..................	7,000	" " "
	1,225,000	" " "

It appears that the sea water brought into the harbor practically furnishes the bulk of the oxygen for decomposing the Metropolitan sewage.

We found that 6,000,000 people required about 260,000 kilograms of oxygen per day to decompose their sewage after it had been screened and settled. We also found that Dibdin's estimate of the amount of oxygen required to completely mineralize the entire organic matter of raw sewage ranged from 462,000 kilograms to 1,386,000 kilograms. These figures I think safely indicate that if floating and visible suspended matter is removed, if sludge accumulation in the harbor is prevented and if the sewage is thoroughly dispersed in the harbor waters the remainder of the sewage can be oxidized by the sea waters to a degree which would not produce objectionable conditions for years to come.

Adeney in his report to your Commission supports the same opinion when he says that: "The harbor waters are quite capable of satisfactorily disposing of the liquid sewage matter from Greater New York for many years to come, provided the solid matter be first removed."

The above figures are, of course, not sufficiently exact to show how long this dilution will suffice for the rapidly growing Metropolis. The present time, however, is not too early to get closer and more exact figures and to ascertain what should be the ultimate remedies which must be applied, after the floating matter and sludge removals have been accomplished to the greatest practicable extent, and the Commission, in my opinion, has wisely considered a number of such further solutions.

Experiences Elsewhere

There are several large cities where sewage has been discharged, untreated or nearly so, into watercourses of brackish or fresh water. The experience there gained is, in my opinion, a more trustworthy guide in forming an opinion regarding the conditions to be expected in New York than any laboratory work, or calculations, as above. I may mention London, Hamburg, Washington and Philadelphia. The Commission is acquainted with most of the details of these cases, but I shall repeat a few general facts and add a few more.

London. The Thames, with a tidal range of 18 feet, receives the sewage from a larger population than New York, and its condition indicates that brackish water of a tidal stream can remain in a satisfactory state with an oxygen content of only 25 per cent. of saturation. I understand it has fallen to 5 per cent. without causing a nuisance. I have been on the Thames on several occasions of low dissolved oxygen and have not noticed the slightest offense.* The sewage is relieved, before discharging, of about half of its suspended matter, and sludge is continually being dredged from the river, this material being mostly due to the accumulation of rain-water washings rather than to sewage. Mr. Fitzmaurice and Mr. Clowes report this disposal as being quite satisfactory.

Besides keeping out the floating matter the only treatment given since about 1891 is precipitation at Barking and Crossness. Of late Mr. Fitzmaurice has expressed the opinion that plain subsidence without chemicals might yet be sufficient to prevent nuisance in the Thames for a number of years. A removal of the suspended matter to as large a degree as practicable and a dissolved oxygen content frequently of 20 per cent. has been found quite satisfactory.

Hamburg. In Hamburg the river Elbe has a tidal range of about 6 feet and contains only land water from which about one-half of the city's water supply is obtained at the upper end of the city. Only floating matter, grit and an almost insignificant amount of sludge is intercepted and removed to outside of the city. The sewage from about 1,000,000 people enters the Elbe within the harbor a few hundred feet from shore and discharges at the bottom of the river from several outlets. The annual typhoid fever rate is only 4 per 100,000. The conditions for sewage oxidation are less favorable than in New York. The water area is much less and the shipping per square mile greater. There is no floating sewage on the river and no sludge, as the deposit is frequently dredged.† In the season of low water, *i. e.,* in the late summer, the dissolved oxygen has dropped to 40 per cent., and still lower, without causing the harbor waters to be objectionable. The water supply of Altona, a city of about 180,000 inhabitants, is taken from the Elbe, about 7 miles below Hamburg, and with double filtration has been entirely satisfactory at all times.

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*This is contrary to official statements which indicate that odors from the sewage are noticeable for about twelve miles above and below the outfalls, although not of sufficient strength to be objectionable beyond the river's banks. Ed.

†Much of the sewage rises to the surface and the solid matters are eagerly sought by seagulls. Ed.

Washington. The sewage of Washington in its raw condition is continuously discharged into the channel of the Potomac river by two outlets 100 feet apart and about 27 feet below low tide. The river is a tidal stream with a range of about 18 inches and no sea water ascends to the city. The flow of the river varies from 2,000 to 40,000 cubic feet per second and during the lowest flow the water oscillates during the tide about 12,000 feet. The dilution has varied from 1 part sewage and 45 parts river water in October, 1912, to 1 part sewage and 234 parts river water in March, 1913. For the minimum flow of the river, which is about 2,000 cubic feet per second, and for the present population of about 350,000 there is a land water flow of 5.7 cubic feet per second per 1,000 persons.

I have seen the surface of the Potomac river both when it was calm and rough, and no objectionable conditions were apparent at either time. The minimum monthly per cent. of saturation with oxygen near the outfall was 50 per cent. for a flow of 4,505 cubic feet per second during August, 1912. The monthly dissolved oxygen figure ranged from 70 per cent. in September to 96 per cent. in February.

All floating bulky and heavy matter, including substantially all grease, is automatically held back at the shore, when passing through a grit chamber, screens and skimming tank. The outfall pipes descend to the river bottom and extend to the outlets above mentioned. Examination of the river bottom and beaches show no evidence of sludge or deposits and the surface of the river is substantially free from oil and sleek. The fishing grounds in the vicinity are called excellent.*

My purpose in calling attention to the Washington case is to show the benefits from the removal of floating matter and of discharging and dispersing the sewage at the bottom of the channel. The dissolved oxygen is amply sufficient to decompose the discharged sewage.

Philadelphia. Studies have recently been made of the Delaware and Schuylkill rivers by the Bureau of Surveys under the direction of Mr. George S. Webster, Chief Engineer and Surveyor, with reference to the effects of discharging into them the raw sewage of the City of Philadelphia from many outlets along the shores. A report on the results will soon be issued and the conclusions drawn from them will be interesting.† They will also facilitate a better comprehension of some of the New York conditions.

Both rivers are tidal streams, the range being about 5 feet. The normal land water flow of the Delaware river is 4,050 cubic feet per second; the minimum flow is 2,030 cubic feet per second. The normal Schuylkill river is 1,270 cubic feet per second, and the minimum is zero below the Fairmount dam. The population of Philadelphia is about 1,600,000, of which 450,000 dwell upon the watershed of the Schuylkill river and 1,150,000 dwell upon the watershed of the Delaware river. Upon the watersheds of both rivers, within 10 miles of the City of Philadelphia, there dwell approximately 2,000,000 people.

The Schuylkill river, below Fairmount dam, has much of the time either slack water or a very slight velocity. Therefore its bed is pretty generally covered with sludge, near its mouth to a depth of several feet. Most of it is in a state of active putrefaction, even in cold weather. The river water in the lower reaches consequently contains very little, if any, dissolved oxygen, and practically none during all the summer months. It is exhausted faster than it can be replenished from the surface. The condition of the river has been foul and objectionable for many years.

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*It should be noted that the Washington sewage is extremely weak, and that the Potomac is a muddy stream and subject to freshets.

†Extensive improvements in the disposal of the City's sewage will be proposed in this report. Ed.

The Delaware river has a good current and forms the chief part of the harbor. The bottom is consequently generally clean, except where, on account of sewer outlets and a reduction of the velocity in the docks, sludge has accumulated and is mostly in a putrefying condition.

The greater part of the water supply of Philadelphia is taken from the Delaware river at Torresdale, about 10 miles above the center of the city's sewage discharge. The water is filtered and the death rate from water-borne diseases is very low. During flood tide some of the city sewage is taken upon the river beyond the water intake, as indicated by the depletion of dissolved oxygen in the river opposite the intake, which depletion has been as low as 50 per cent. under extreme conditions of high tide and drought in the late summer.

As the water flows down the river from this point it receives the sewage of the city from one outlet after another. Both the sewage and the deposited sludge in the docks continuously extract oxygen from the water. Although there is constantly also a fresh absorption of oxygen at the surface, the depletion during the summer of 1912 was greater than the absorption, so that opposite the center of the city (Arch Street), about 500 feet from shore, the dissolved oxygen was reduced to an average of less than 20 per cent. between July 1 and September 20, 1912, and yet during this time there was no odor whatever at such localities in the Delaware river.

Below the mouth of the Schuylkill river no more Philadelphia sewage enters the Delaware river, and as the water flows down stream the dissolved oxygen increases from about 30 per cent. to 60 per cent. in seven miles; which indicates that the absorption from the air at the surface of the river is sufficient to double the average dissolved oxygen content of the river water, in addition to replenishing that required for oxidizing the entire flow of sewage from the City of Philadelphia.

The rate of increase of the dissolved oxygen in the Delaware river below Philadelphia from the mouth of the Schuylkill river to Chester, or 7.9 miles, the rate of flow being about 2 miles per hour, was computed by Mr. Webster to be 8.6 pounds per second per square mile of river surface, or 743,040 pounds per day.

If we assume that the absorption area for the sewage in the Delaware and Schuylkill rivers between the points where sewage is first received and the point where the Delaware has recovered its normal condition is about 28 square miles and the population whose raw sewage enters the river is about 1,800,000 persons, then on the average 1 square mile of river surface will serve about 64,000 persons. The sludge is practically removed by deposition near the sewer outfalls and in the Schuylkill river. If the organic and volatile matter contained in sewage is 77 grams per capita per day, then the amount of such sewage matter which is decomposed by the oxygen absorbed from the air on one square mile of flowing land water surface should be on the average nearly 5,000 kilograms or 11,000 pounds per day.

Recommendations of the Commission

In taking a very broad view of the entire subject, the Commission has given thought to almost every conceivable solution of the problem before it. At the outset, after brief consideration, it has ruled out some of them as impracticable on account of the cost. Thus the Commission rejected a single distant sea outfall and the treatment of the sewage at one or at several plants by oxidation in sprinkling filters or on irrigation fields. These rejections are proper, and any serious consideration of such means for disposing of the Metropolitan sewage should be permanently abandoned.

The Commission has not considered any solutions for the disposal of the sewage from New Jersey, lacking authorization to do so. It has, however, given that disposal such general consideration that the recommendations for New York would allow similar recommendations to be adopted for the sewage of New Jersey, quite independently of those now suggested for New York.

The New York portion of the Metropolis has been divided into four subdivisions. In all of them the sewage is collected so that it can be delivered at points as near as possible to some deep, tidal channels.

This division has the advantage of giving relief to the most important points at the earliest possible day, and of making it practicable to apply a relief either to one division or to another, without waiting for the completion of the whole system.

I shall refer to those divisions not in the order given by your Commission, but in an order which will, I think, better facilitate the giving of my opinion as to "the necessity and sufficiency of the plans proposed." I have also separated your second division into two, calling one the "Hudson river" and the other the "Lower East river" division.

1. *Hudson River.*

The territory included in this division is the entire west side of Manhattan Island, which now drains into the Hudson river. You say (Prel. Rpt. VI, page 39): "The water of the Hudson will be capable of assimilating the sewage produced on the west side of Manhattan Island."

I am fully in accord with this view. You propose that the dry-weather sewage "should be passed through grit chambers and screened and so discharged into the water as to insure prompt diffusion." This recommendation likewise in general accords with my views.

For the final detailed plans every single outfall should be specially studied. In some cases it may be more effective, if desirable and if there is sufficient space, to have the suspended matters retained by floatage rather than by screens. There can be no objection to having gravel or sand enter the harbor hereafter as heretofore, and it is cheaper to remove it by dredging from the harbor than by hand from basins or chambers.

Where, however, fine screen are preferable for local reasons then grit chambers are necessary to protect the screens and facilitate their operation. Grit chambers are also necessary where coarse heavy material is expected and the sewage, having contained such grit, is to be pumped or carried quite a distance from the shore to the point of outfall. Where the gravel and sand can be discharged into the river at the shore, as now, to be removed by dredging, and only the sewage discharged further out into the channel it would be economical to do so.

I heartily agree also with the proposition that the sewage be discharged as nearly as possible into the channel current by means of submerged pipes having a number of openings discharging as nearly horizontal as practicable. It is the best of the simple means of dispersion of the sewage in a current. I am aware, however, of the difficulties encountered when considering the interests of navigation. Where the channel has a depth well below the established harbor depth there should be no difficulties. Otherwise satisfactory agreements must be made with the United States Government.

2. *Upper East River and Harlem.*

The plans you have proposed for this second division have the object of removing the present pollution of the Harlem river, to provide for a proper sewage discharge into the Upper East river and to prevent a large part of the present pollution of the Lower East river during ebb tide. You have divided the area into five subdivisions, which seem to have been carefully limited, so that the best conditions for collection and discharge have been reached.

The outfalls are all located at favorable points, where the water is deep and the currents are rapid. The general locations are favorable also towards keeping the sewage discharged well towards Throgg's Neck, or rather as far away from the Lower East river as practicable.

The Harlem river for a large part of its length is quite objectionably polluted both by sewage and by sludge deposits. The only solution of the Harlem river problem is, first to keep the river well dredged and free from sludge deposits and to intercept the sewage now discharged into it.

You have selected the northeast part of Wards Island as the place where the sewage from the Harlem subdivision is to be delivered and treated. This location for an outfall is a good one and there is sufficient room apparently available for the intended purposes.

It would be of little avail to discharge the sewage intercepted from the Harlem river at a nearer point, because much of the sewage would quickly return with the tide. On Wards Island it is discharged into the Hell Gate current, where, after intercepting the floating matter, it would be lost to view. Sufficient land should be secured to erect also settling basins for the retention of the sludge as soon as this will be found necessary.

Rikers Island is unsuitable for sewage treatment for evident reasons. Sunken Meadow, although beset with other difficulties, is the only alternate practicable location in the neighborhood, if Wards Island should not be available.

If the East river is deepened and the channel widened, as proposed, the conditions for dispersion of the Harlem river sewage and for its oxidation will be improved.

The location for outfall and treatment works at Clason Point, as proposed by your Commission, is apparently the best one for discharging the sewage from the area that you have drained to it, into deep water as quickly as practicable.

The outfalls for the remaining three subdivisions, situated on the southeast side of the Upper East river, are also well located to get a thorough and quick dispersion of the sewage at depths of at least 30 feet and from as many outlets across the current as practicable.

In all cases the outfalls appear to require the least expenditure of money for collection as well as disposal.

You have quite properly recommended screening and retention of the floating matter at all of these outfalls. The outfall sewers should be so designed and pumping stations so placed that it will not be difficult to install suitable settling tanks hereafter, when they may be required by the condition of the river. In my opinion sufficient land should soon be secured in every case where plants are required for use in the future.

Regarding sewer systems for collection, you very properly prefer the separate system where sewage is to be pumped and treated to a high degree of purity. You also approve of the custom that where sewers are already built on the combined system this system should be continued.

For the last 35 years it has been recognized in Europe and America that the separate system is the better one, because more economical when the sewage must be given a high grade of purity, when it must be pumped and when subsurface storm water removal can be postponed, but sewage removal is an immediate necessity.

Where the combined system has been built you naturally do not consider it wise to change it, because the advantages in the cost of any treatment would not be balanced by the cost of a new installation of sewers.

3. *Jamaica Bay.*

The Commission has reported two projects for the division which naturally drains into Jamaica bay. One confines the sewage disposal to its own area, the other considers a combination with the sewage from the subdivision, which is to be mentioned under caption V. Here only the first one will be considered. Whatever may be the specific plan of development of the Jamaica bay division, it is clear that no raw sewage should be permanently discharged into it, that whatever sewage flows into it naturally should receive a treatment to prevent all nuisance, and that the treatment in the future should be of a higher order than in any of the other sewerage divisions because the effluent enters a small and shallow inland bay.

The plan of the Commission is to intercept the sewage of the whole territory and deliver it at two points. One point is Jo Co.'s Marsh, an island in the bay, to which is delivered the sewage from the area of the eastern subdivision between Rockaway in the south and Creedmore in the northeast. The other point is Barren Island, to which is delivered the sewage from the area of the western subdivision between Coney Island and Jamaica.

The sewage is to be collected by the separate system so far as possible, otherwise it is to be intercepted from combined sewers, to allow as little as possible of the first street surface washing and sewage to get into the bay. The first wash from the streets, whether in the combined system or in the storm drains of a separate system, being often quite polluted and sometimes more so than American dilute sewage, it should be intercepted in both systems and turned into the sewers for purification and thus prevented from reaching the bay.

I entirely agree with your Commission in opposing long canals in this territory for the reception and discharge of sewage. They would certainly become a nuisance and injure, if not stop, the development of the nearby territory. Such canals, if built, should be for the removal of surface water alone, and the house sewage should be carried to its final discharge in separate pipes. The additional cost of the separate pipes would be more than repaid by the improved value of the land near the canals.

The treatment works on Barren Island are estimated to require about 100 acres, which can be furnished with settling tanks and further means of treatment by sprinkling filters, if required. The location seems well adapted for a final disposal of the sewage and for giving it whatever treatment may be necessary. This point of discharge, after the sewage has had its floating and suspended matter removed by sedimentation tanks, is, in my opinion, the best one now available. It insures a sufficient dispersion and high dilution of the tank effluents, so that in my opinion at no time in the future any objectionable results would appear, either in Jamaica bay or along the beaches of Coney Island or Rockaway.

The treatment works on Jo Co.'s Marsh would be for the purpose of discharging the effluent into Jamaica bay at all times. This location also appears to be the best one for treatment works and you have estimated that 30 acres of land be reserved for them.

Owing to the confinement in the bay the treatment should be more thorough than at Barren Island. Besides sedimentation there should at once be an oxidation of the effluent by sprinkling filters and then a discharge near the bottom of the bay.

I do not believe that the effect of final settling basins would eventually be worth their cost under the conditions of this outfall. Only if the oyster and clam industry in the bay is not abandoned, as in my opinion it should be, and eventually certainly will be, will it be necessary to add final settling basins in order to have the effluent dosed with disinfectants so as to reduce the danger of infecting the shell-fish.

You have also studied the case where a pumping station and settling basins, erected near the bay side at Arverne, would allow the effluent to be more economically and efficiently discharged about 4,000 feet from shore into deep water and ocean currents. No floating matter would drift towards the shore and no depositing matter would interfere with navigation or drift landwards. The liquid sewage would be readily oxidized in the large current of sea water into which it discharges.

This project appears to me to have much merit. If a discharge into the ocean is found to be more economical it would be also more effective and offer a greater protection to the inhabitants than a disposal in the bay, because the effluent water flowing out is liable to have contact with a long shore line, instead of being carried away in a current parallel with and several thousand feet away from the shore. In neither case would there be floating matter to strand nor sludge to drift ashore.

4. *Richmond.*

The disposal of the sewage from Richmond affords few difficulties. The sewers now existing are built on the combined system, except in a few instances. It is the intention to carry the sewers to the pier heads for discharge. At a number of points this plan may not be satisfactory, even if the sewage is discharged into deep water, this is, as far as practicable from shore, as you have intended in the other divisions.

You state that the most favorable place to ultimately discharge the sewage is at one point in the tidal waters near the Narrows, but that this would not be economical. I fully agree with you regarding this conclusion.

You have, therefore, subdivided the borough into areas and have collected the sewage in each one, so as to separately dispose of it at economical points. It is, of course, very much better to discharge the sewage at the bottom of a good channel than at the shore. But it may in some cases be more economical to do the latter than to gather the sewage by interception to a few points, at which submerged pipes are carried out into the channel. In my opinion it will be a question for local study and estimate to decide between the two plans. As a general proposition numerous outlets give a better dispersion than a single one into the same current, but there should be a current between the outlet and the shore.

While I consider it a wise policy to secure and retain in this division sufficient land at the proposed outfall stations for treatment works, such as the Commission has proposed, I am convinced, with the Commission, that such treatment need not be more at the present time than to keep out of the bay all floating matter and in the Arthur Kill and opposite Newark bay also the sludge. Experience will indicate how soon in each case a more thorough purification is required. The works should therefore be so designed that they permit additions to be made for more complete treatment when necessary in the future.

Regarding grit chambers, the remarks made above would apply also here. When settling basins are required, it seems to me cheapest to take the sludge out to sea than to dispose of it nearby, unless the sludge is of the inoffensive kind.

5. *Lower East River.*

When discussing above the subject of dissolved oxygen in the harbor waters, I expressed the opinion that, if the floating matter of the sewage were removed and the sludge prevented from accumulating on the harbor bottom, the remainder of the sewage could be oxidized in the harbor waters for some time without objectionable effects.

This opinion related to the average of the entire harbor. Unless there is a uniform distribution of the sewage within it, the conclusion would not apply under present conditions to every part of it. The Lower East river is without question, at present, the most polluted part of the harbor, not mentioning the Harlem river, and any permanently satisfactory solution for the entire harbor should embody means for removing especially the aggravated evils of this portion.

You have recommended such a solution by collecting the sewage now entering the East river and taking it to an artificial island to be built in the Lower bay, between Coney Island and Sandy Hook, there to be discharged, after whatever treatment might be necessary. The expense of construction and operation of this project is large. In justification thereof you have given a number of reasons. I shall now comment upon them and feel obliged to maintain the view that the adoption of this project is not warranted at the present time.

You first mention the large areas of low and made land in lower Manhattan and Brooklyn which causes the main outfall sewers to be of very flat grade and for large areas below high water. These conditions are not satisfactory. They cause the sewage to deposit much of its suspended matter, which putrefies and develops offensive odors from gases and air escaping at the manholes, and the putrefying sludge is flushed into the harbor by rainstorms. The sewage is generally somewhat septic when discharged, but if it is discharged at the bottom of the harbor and beyond the pier heads the septic condition would soon be removed by the dispersion of the sewage in oxygenated water. Some of the sludge, having entered into decomposition in the sewers, will have correspondingly less decomposition to undergo when deposited on the harbor bottom.

To overcome the objectionable condition on shore, within the areas where the present sewers are below high tide, it has long ago been suggested to build separate sewers for sewage removal, with better grades than at present and to lift the sewage by pumping. This suggestion still has merit.

You further mention some of the present physical conditions of the sewers, which are undoubtedly objectionable, such as the lack of cleanliness, accumulation of sludge and grease and comparative uselessness of many of the catchbasins. The objectionable condition of the present sewers, if they are not rebuilt, can be removed by more care in the maintenance and operation, whatever is eventually done with the sewage itself. Wherever sufficient slope is practicable, it is generally cheaper to omit catchbasins and let the silt and gravel enter the sewers and be flushed to the rivers, there to be taken out by dredges.

You refer to the most conspicuous nuisances of the Lower East river, which are Newtown creek, Wallabout bay and Gowanus canal. I am satisfied, from what has been said above, that the very objectionable conditions existing in all three localities will disappear if the floating matter and the sludge deposits are removed. Since the flushing channel for the Gowanus canal has been built the canal is still offensive, notwithstanding the clear water which now enters it. This fact is due to the fact that much sludge still covers the bottom of the canal, putrefying and sending up foul gases and comminuted sludge particles, which persist long enough to reach even the East river, to deposit among the docks near the new outfall. Keeping the bottom of the Gowanus canal clean by suction dredging will, in my opinion, prevent the continuation of the nuisance arising therefrom.

Wallabout bay and Newtown creek can, in my opinion, be treated in a similar way by the removal and proper disposal of the floating matter and the sludge deposited therein.

In these cases, as well as in many others, where the sewers discharge below high water it would be advisable to lift the ordinary dry-weather flow with electric pumps into settling basins, where the sludge may either be digested or frequently removed before digestion, in special barges, as mentioned above.

I quite agree with the Commission that in the collecting system the sewers should have the first right of way beneath the city streets. A gravity flow of water, as in a sewer, carrying suspended matters demands a regular grade. All other structures, such as pipes conveying potable water, gas or steam under pressure, as well as a number of other conduits and subways, can more readily change their grades.

The facts that the flow of sewage into the harbor is irregular as to time and that the flow of tidal water, in addition to not being uniform during one tide even, reverses its flow, contribute to getting a better mixture than if there were a more regular and constant flow, as a uniform discharge into a fresh-water river.

Sludge settles more rapidly, and by the occurrence of some coagulation more thoroughly, therefore it can be more expeditiously gathered in salt than in fresh water.

The tables which your Commission has prepared indicate the relative value of the different bodies of harbor water for oxidizing sewage. They show that the Lower East river receives more organic sewage matter than any other part of the harbor, and that the water available for its dilution and oxidation is less per capita than in any other water of the harbor, excepting the Harlem river.

There can be no question but that the sewage flowing into the Harlem river can be intercepted and removed into the Upper East river, because it is the only solution possible for relief from its nuisance, as mentioned above. I cannot, however, see equally good reasons for intercepting and removing to the Lower bay the sewage from the Lower East river, as the Commission has suggested.

The chief reasons for this opinion are, first, that screening and sedimentation and a sludge removal by suction dredges from the docks and river bottom in the Upper and Lower East rivers, perhaps also oxidation of a part of the sewage on Blackwell's Island, will, from what has been said above, in my opinion, remove all causes of offensiveness to sight and smell, not only now but for some time to come.

Secondly, that the remaining liquid and fine suspended matter, as well as some sludge deposits that escape deposition, can, in my opinion, be sufficiently oxidized by the waters of the Lower East river and Upper harbor to prevent any nuisance.

Thirdly, that the cost of removing all sewage and some rain-water to the "Outlet island" is so large that, in my opinion, the relative benefits to be gained in excess of those gotten by local and partial treatment, as above suggested, are at the present time not justified.

The New York harbor waters have a high financial value to the city as a sewage oxidizer, and this asset should be as completely utilized as practicable before a limitation is fixed involving such large expenditures.

A number of engineers, sanitarians and biologists in their endeavor to select a figure which would represent the lower permissible limit of dissolved oxygen in waters receiving sewage, have suggested the figure 50 per cent. or thereabouts, below which the water might be objectionable. No strong reasons have been given to use this figure as a limit, even as an average limit.

The experience above quoted from London with its tidal brackish water, and Philadelphia with its tidal fresh water, indicate that a much lower average figure does not cause a nuisance. Theoretically, only a reduction to zero at any point might mark its beginning.

It has seemed to me that much of the evidence which has led to the round figure of 50, or half saturation, was gained from practical observation of cases where sludge was putrefying on the bed and where floating matter, scum and sleek were adding to the extraction of oxygen near the surface.

If both sludge and floating matter are removed the oxygen content of the water is improved. A condition is thereby created which allows without objection a lower degree of saturation with oxygen to be maintained than otherwise, because of the absence of most of the non-resistant suspended matter, floating or attached to gas bubbles and liable to rapidly exhaust the oxygen, become putrescent and cause odors.

Regarding major fish life, which I have already mentioned, I do not consider this industry, so far as the Lower East river is concerned, of sufficient value to justify the heavy expense of maintaining for it a higher degree of oxygen in the water than might otherwise be entirely satisfactory.

Irrespective of the large expense of the tunnel outfall sewer and of the large pumping stations, and owing to the uncertainties and difficulties to be encountered below tide level when crossing Long Island, to the proposed Outlet island, possibly incurring a larger expense than is now estimated, it is questionable whether, after the sewage arrives at the island the subsequent condition of the sewage and cost of its treatment will be justified.

The tunnel is suggested to be built large enough for a reasonable future. It will, therefore, at the outset cause a correspondingly slower velocity than in later years. The natural condition of the sewage, therefore, when arriving at the island after about 12 miles flow would at least at first be septic, that is, offensive.

You propose to prevent this result "by aeration to be provided at two or possibly three points along the lines." I am not convinced that such a means would accomplish the desired result. I have recommended aeration at a pumping station by injecting air into the force main under a fairly good pressure which causes the air to be dissolved and dispersed throughout the water section. I am not sure after the pressure is reduced what the practical results as regards odors will be, in part due to the release of air and remaining foul gases escaping with it. But I believe it will be difficult, if at all possible, as a permanent measure to aerate the large sewage flow in a gravity sewer across Long Island, as shown in the profile, so as to penetrate the sewage sufficiently to accomplish the desired oxidation.

The following treatments at the island are possible:

First, the sewage on arrival at the island could be discharged in a raw condition. The large quantity of raw sewage with much comminuted matter might sometimes be unfavorably noticeable in its effects. The Commission, therefore, properly proposes to treat the sewage before discharge.

Secondly, the sewage can be passed through large settling basins—the Dortmund type is suggested by your Commission—in which the sludge is allowed to deposit and to be later taken out to sea. The effluent is discharged into the bay.

As the suspended matter after flowing 12 miles is highly comminuted, the time required for settling on the island, the greater portion of the solids will be increased. To get the same result as with shorter outfall sewers the basins would have to be larger and more expensive than if nearer the point of sewage origin. The sewage, if discharged without bacterial or chemical treatment, would have more dissolved matter to be oxidized in the Lower bay than if discharged in the Upper bay, which might be an advantage.

The sewage rises from the end of the long tunnel into the open basins. Unless aerated at the pumping station, the odor would be stronger at these basins on account of the age of the sewage than at any point where it might be exposed along the East river. This septic sewage odor has occasionally been perceptible a mile distant. Just how much this odor could be reduced by a single aeration at the pumping station I am not prepared to say.

The application of a disinfecting, coagulating and precipitating, oxidizing or aerating plant as suggested would add correspondingly to the cost. If any of such plants were resorted to at the Outlet island the results could be no better than if used near the East river; for instance, on the shoals below Governors Island, except that in the Lower bay any nuisance could not be so readily perceived. An oxidizing plant in the Upper bay in the form of coarse-grained filters or other means, is not liable, other things equal, to be as septic and odorous as at the more distant island. A disinfecting plant would probably not be necessary at any point in the harbor and an aerating, precipitating and sludge plant could as well be placed in the Upper as in the Lower bay, and from experience elsewhere need not be offensive. The advantages as regards treatment works on the Outlet island in the Outlet island in the Lower bay over a treatment nearer by do not appear to me to be very material. At any rate, I believe the decision can be postponed without any danger to health or from a continuation of the present nuisance, if suspended matters and sludge deposits are removed.

The new island in the Lower bay could be made strong enough to resist the effects of wind waves in high storms, but it will be expensive to do this, and it will require the continuous presence on the island of a suitable force of men.

I am informed that your Commission is considering treatment of the Lower East river sewage on Governor Island or on the shallow area south of the same. If physical and legal conditions permit, I consider such a project preferable to the Lower bay project, not only on account of less cost, but of better control. The effluent could be discharged into the waters of the Upper bay and Hudson, which your Commission have found at present to be those which are least charged with sewage.

The treatment works have been considered by you as consisting of sedimentation tanks, such as those of the Imhoff type, giving inoffensive sludge. If the collecting sewers are kept well cleaned there is no reason why the sewage when delivered should not be inoffensive, and therefore, why oxidation by means of sprinkling filters or other means would not also be an inoffensive process. Owing to the scarcity of land available, the works would have to be designed to give the greatest intensity of treatment. The degree to which such treatment is carried, however, need not be higher than the character of the Upper bay water justifies.

I am not of the opinion that a sewage treatment plant on Governors Island or on any other area below would be necessary at once. I believe, however, that studies should now be made far enough ahead to determine the approximate time when an oxidation of the sewage should follow the present necessity for removing the solid matter, that land should be secured while it is available, and a project soon adopted which will best serve the city in the more distant future.

The Commission gives the ratio of crude or raw sewage to the harbor water in the Lower East river division at 1 : 244, while that for the Upper bay is 1 : 2920. Therefore, when the sewage going into the Lower East river must be oxidized it appears that the Upper bay can receive for some time without detriment a very large part, if not all of it, as well as the New Jersey partially treated sewage.

I do not hold the opinion that, considering the oxidizing power of the New York harbor water we should depend only upon the tidal prism, with the ratio of sewage to water as 1 : 32.3, nor upon the net ebb flow, with the ratio of sewage to water as 1 : 5.9 as taken from your tables. The waters of the entire river section are well intermingled, as pointed out by the Commission through its dissolved oxygen figures; therefore, it seems to me that we should not apply the latter two ratios to the pollution of the whole water capacity with which we are dealing.

The first ratio given above, namely, 1 part sewage to 244 parts water, would correspond more nearly with the actual dilution than the ratio of 1 part to 32.3. But it can be considered only as an average at present with wide local variations.

The Commission further says: "It is wrong to speak of sewage matters as sewage 2 or 3 hours after they have been discharged into a tidal estuary. Some of the ordinary ingredients may still exist, but the chances are all against the continuance of any of them in an unaltered condition, except the grosser solids and such others as may be able to persist in greatly diluted form."

This statement confirms the fact that soon there is a separation of floating and depositing matter from the dissolved and fine suspended or colloidal matter, that more and more matter is continually dissolving and that the arguments relating to crude sewage then no longer hold. There is a substantial separation of the sewage into three parts, each one of which must later be given separate consideration, because each becomes more and more unlike the others in character and quantity and ultimately requires separate treatment. The conclusions reached from data relating to raw sewage, therefore, cannot be applied to any one of its three parts after it has passed its first stage of disintegration.

As the only one of the three parts of the sewage which can be left in the harbor water is that representing the liquid and fine suspended matter, and also the part most quickly oxidized by the water, it is my opinion that the amount of sewage represented by the liquid portion which can be digested by the harbor water will be materially larger than that which has been deduced from the usual laboratory experiments.

The Lower East river should therefore be able to receive the liquid and fine suspended matter reaching it for many years longer than it can receive the crude sewage. When the limit has been reached beyond which offense would occur some of this liquid sewage may be intercepted and carried elsewhere to be discharged, at first perhaps directly into the less oxygen-depleted waters of the Upper bay and later receive some oxidation or other treatment before its final discharge.

All the floating matter in this division should be intercepted at once and the solid matter collected in settling basins where practicable, or otherwise frequently removed from near the sewer outfalls by suction dredges.

If the outfall sewer to Outlet island should be built, the western branch of the Jamaica bay intercepting sewer, as you have proposed, would also be connected with it, instead of discharging at Barren Island. If Outlet island is not built, the Barren

Island project as outlined by you would give a good disposal for the sewage from the respective territory.

Résumé and Conclusions

The sewage problem in New York is more complex than in any other large city, as the work of your Commission has demonstrated. Its solution depends upon scientific knowledge and practical experience.

It can be aided by results satisfactorily obtained elsewhere under similar conditions.

It depends also largely upon the opinions and desires of the inhabitants. Some conditions and some people will demand higher standards, and therefore generally greater expenditures for some cities than for others. This circumstance has occasionally made the solution difficult and slow of adoption.

Municipal expenditures should be divided in such proportions among the different demands of a community that the results obtained are fairly well balanced in all directions. No excessive benefits should be secured for one public work at the sacrifice of having an insufficient benefit from another. For instance, in my opinion we should distribute the expenditures for the collection and the disposal of the Metropolitan sewage in such proportion that the works for collection, because nearer to our inhabitants and the locations where we spend most of our time, receive an expenditure which will give equal benefit to that which should be desired from the final disposal of the sewage. In Europe this proportionate expenditure generally receives more attention than here. Sir Robert Rawlinson, who may perhaps be designated as the father of modern sewerage, asked: "Is it better to pollute rivers or pollute towns and houses—to kill fish or to kill men?"

In seeking a solution the Commission has taken a broad view and collected a very large amount of information, which is and will be valuable in solving the sewage problem of the Metropolis. It has made surveys, analyses, inspections, compilations and studies to a greater extent than has ever been done before.

The problem may be divided, in my opinion, into three groups: one relating to health, another to nuisance and the third to cost.

The health factor is judged by the liability of the works, devised for collecting and disposing of the sewage, to transmit disease germs from sewers, bathing, consuming shell-fish and having contact with stranded objects. The nuisance factor is judged by the offensiveness to sight and smell. The cost factor is judged by the ability and willingness of a community to pay the price of the improved conditions.

The physician usually deals with the first, the engineer with the second and the public must deal with the third group.

Experience has shown that works intended to prevent a nuisance usually prevent also the transmission of disease germs. The problem in its most abbreviated form is, therefore, reduced substantially to cleanness of sewers and harbor and to the most economical means of securing this result. The cost should be considered in terms of the desired degree of relief from unhealthfulness and nuisance, which in the case of our Metropolis will, I feel sure, not be unreasonably limited.

The work of the Commission has been extended chiefly to the problem of sewage disposal. It has made a very thorough study of the application of all of the known means of sewage treatment for the entire Metropolitan area. It has also examined into the treatments found elsewhere. Although sewage varies in quantity and quality according to the character and occupation of the population, it is remarkably similar in its behavior under the different conditions, both when discharged into water or upon land. Experiences in even somewhat dissimilar cities can, therefore, be utilized and furnish help to form opinions in new cases.

The Commission has accepted the latest theories of sewage purification and of the means of judging and measuring the most efficient conditions and results.

It has made extensive analyses of the harbor water at different locations and depths, both chemically and with reference to bacterial contents, and especially to those indicating the presence of sewage. It has made these analyses at different stages of the tide and at different seasons. It has studied the currents and the circulation of the harbor waters more in detail than was done before.

The Commission has accepted the recent conclusion that sewage and its suspended matter, which once on theoretical grounds was considered valuable on land and here and there was temporarily sold at good prices, is now on practical grounds considered much less valuable than originally supposed, and is moreover liable to become a nuisance. The conclusion at the present day in most cases, therefore, is that sewage should be purified by nature's method of converting dead organic matter into mineral matter by biological processes. The natural methods are: in water an oxidation by the oxygen contained in solution, and on land by the oxygen contained in the air.

I agree with the Commission that the floating sewage matter, recognizable as such, should be removed and that no thick films of grease, oil or tar should be seen upon the waters, although small quantities of oily sleek should be permissible as unavoidable in a harbor.

I also agree with the conclusion that no sludge accumulations should be allowed in the harbor, and particularly in the docks and slips where it is most likely to be. A higher standard might well exist for the water in the docks and slips than for that out in the channel.

I do not consider it practicable to make bathing safe within the harbor, nor to consume shell-fish that are taken within the same.

Nor do I consider it practicable or advisable to fix upon any uniform standard of cleanliness or of oxygen contained for the waters of the entire harbor. In those of its parts where economy demands a greater digestive power for the sewage without producing any nuisance, the standard may well be lower. Where it is not economical to draw down the oxygen content very low it will, of course, be advisable to maintain a higher standard. If any standards may be fixed in the different parts of the harbor they should, in my opinion, be based on the most economical means for preventing a nuisance from arising at any time.

I accept the Commission's conclusion that wherever possible the sewage should be discharged through submerged outlets into a current the nearest available, and not at the shore. Whatever means are practicable they should secure as great a dispersion of the sewage in the current as possible.

In order to prevent floating matter from entering the rivers, screens, settling basins or floatage chambers should be built at the sewer outlets.

Grit chambers are suggested by the Commission to collect the grit from the sewage. It is cheaper to dredge the grit from the river than to take it out of a grit chamber or catchbasins. It is necessary, therefore, to determine in each local case which disposition should be made. Where Imhoff tanks for sludge digestion are built or where the sewage must pass through pumps it is usually found better to previously intercept the grit for separate removal.

I do not consider the existence of turbidity due to rainfalls in the drainage area of the Hudson valley objectionable even if it were preventable, which it is not. Nor do I consider a very slight discoloration of the water objectionable, such as we practically find in all harbors.

Where, particularly in the lower part of Manhattan, the sewers are below high-tide level and have a very flat grade, it may be found quite advantageous and economical to rebuild such sewers and to erect electric pumps so as to increase the velocity of the sewage, to keep the sewers cleaner than they are now and to give the sewage quicker discharge, obviating to a great extent oxygen exhaustion before entering the river.

I cannot accept the Commission's conclusion that the average oxygen contained in the harbor should not fall below about 58 per cent. of saturation. If the object were to maintain the life of major fish I am of the opinion that the value of having the fish in the harbor is insignificant when compared with the cost of maintaining such a high standard of oxygen saturation. If the object were to prevent a nuisance, then we must realize that no nuisance is caused so long as any oxygen remains in the water. If this latter is the object of fixing so high and therefore so expensive a standard, I am of the opinion that the sludge removal in the harbor, and chiefly from the localities near the sewer outfalls, will tend to raise the percentage of dissolved oxygen, and it will also tend to cause the oxygen depletion to be more uniform in the harbor waters than it is now, although the uniformity is even at present higher than might be expected. The safety, therefore, of lowering the permissible percentage of saturation is correspondingly increased before the probability arises that at any locality the dissolved oxygen might entirely disappear.

There are a number of cases at large cities where the percentage is much lower than that proposed for New York without causing the slightest nuisance. If the London standard of 25 per cent. were used in the New York harbor it would give the New York waters double the amount of oxygen for sewage decomposition than the standard proposed by the Commission. This fact would postpone for years the necessity of building works for taking any sewage to the Lower bay for oxidation in its waters.

I consider a standard of 25 per cent. with frequent sludge removal from the harbor bottom a safe protection against any nuisance arising from the water.

I agree with the Commission that the Metropolitan area should be divided into a number of drainage districts, each of which requires somewhat different solutions.

I also agree to the suggestion that to carry out the most efficient works for the entire harbor general plans should be made by a central authority and that this authority should control the execution of such plans for the entire Metropolitan area of both the State of New York and the State of New Jersey.

We find central authorities controlling the disposition of the sewage for a group of communities in Europe, and also in our country. The chief advantage of such central control is to have harmony in the works, to economize in the total expenditure and to effect a satisfactory disposal for a distant future as well as for the present time.

To recapitulate:

The first remedy required, and one which you have proposed, and in my opinion the first one in importance, is to intercept all visible floating sewage matter which now disgracefully covers large areas of New York harbor.

The second remedy, and in my opinion second in importance, is to stop the further deposition and putrefaction of sewage sludge on the bed of the harbor, chiefly near sewer outfalls, and in the meantime to frequently remove the present sludge accumulations by suction dredging until sufficient land works are built to intercept the sludge and prevent excessive amounts from depositing in the harbor.

The third important remedy, after having substantially freed the harbor from its floating matter and sludge, is to distribute the sewage thus partially treated by such additional sewers to points in the harbor where the dissolved oxygen will naturally oxidize it to a satisfactory degree, which degree must be determined largely and finally by actual experience.

The fourth remedy is to convey any excessive amounts of sewage which cannot be satisfactorily oxidized by the harbor waters alone to the nearest and most suitable areas on land for artificial oxidation, as proposed by the Commission, and if sufficient land areas are no longer available for treating all of the excess, it would then be necessary to convey this excess to the nearest bodies of available water and distribute it in them so that it will get the required oxidation.

I do not consider it necessary to take the last-mentioned steps at the present time. A better time than now to decide this part of the problem, in my opinion, is after the first, second and third remedies have been applied, when it will be more practicable than now to determine whether or not the percentage of dissolved oxygen remaining in the harbor waters justified the expenditures of taking the excessive amount of sewage to the Lower bay.

RUDOLPH HERING.

DECEMBER, 1913.

CORRESPONDENCE CONTAINING MR. HERING'S ENDORSEMENT OF THE COMMISSION'S RECOMMENDATION FOR THE GRADUAL CONSTRUCTION OF THE LOWER EAST RIVER PROJECT.

March 13, 1914.

RUDOLPH HERING, ESQ.,
170 Broadway, New York City.

DEAR SIR: Since your report of November, 1913, was submitted, some of the opinions and projects relating to sewage disposal upon which that report was based have been so altered in preparation for this Commission's final report that it seems desirable to bring the changes to your attention and to ask your opinion in regard to them.

The changes made affect the minimum percentage of dissolved oxygen permissible for the water and the Commission's plan for the protection of the Lower East river. These are the only two subjects upon which you were not in substantial accord with the Commission's views when your report was made.

With respect to the oxygen question, this Commission considers that it will not be necessary to include a restriction as to oxygen in the standard of cleanness which should be established as a guide in protecting the harbor against sewage, for if the other provisions of the standard are complied with, there will, in the opinion of the Commission, be sufficient oxygen in the water to answer the requirements.

With respect to the plan for the Lower East river, the Commission expects to recommend that the same principle of gradual construction be adopted in building the main drainage and disposal works which will be necessary for the Lower East river as the Commission has advised in the projects which it has proposed for other parts of the city. Instead of carrying out the ocean island project with its interceptors, siphon, pumping station, main, island and settling basin disposal plant as one undertaking, only the first stages in the execution of this comprehensive plan would be undertaken in the near future.

The works to be taken in hand at first would be, for Manhattan, an intercepting sewer running along the Manhattan water front from the Battery at the south and 26th St. at the north to a point near Broome St., where a screening and pumping station would be located. The screens would operate upon the most efficient principle for fine screens. The sewage, after screening, would be discharged well out from shore at the bottom of the river through multiple outlets.

On the Brooklyn side, the sewage would be collected by an interceptor from Classon Ave. at the south to Newtown Creek at the north to a point near South 8th St., where it would be passed through screens like those on the Manhattan side of the river and pumped through submerged outfalls lying on the river bottom to a distance sufficiently far from shore to insure immediate and thorough diffusion.

The sewage from the rest of the Lower East river territory in Manhattan and Brooklyn would be collected for screening and discharge probably to as many points as there were sub-divisions or principal drainage areas. When, after these works are carried out, it is found necessary or desirable to afford further protection to the Lower East river, the city can proceed to construct the siphon to carry the sewage of Lower Manhattan beneath the East river to the Brooklyn shore, where, after joining the sewage from the screening plant at South 8th St., it would be pumped to sea.

In the final development of this plan, it will be necessary to construct the pumping station on the Brooklyn side, the main to the ocean outlet and the island, where the sewage will be treated before final disposition. No part of the original construction will have to be discarded except the submerged outfalls.

The Commission believes that the idea of proceeding in the manner indicated toward the gradual and ultimate construction of the ocean island project may meet with your approval, inasmuch as you consider that it will not be necessary to divert a large amount of sewage from the Lower East river and that screening and discharging the sewage beneath the deep, strong currents of the East river will permanently meet the requirements of the situation. The Commission is of opinion that the ocean island project will be recognized as a necessity before many years and is willing to leave the correctness of its opinion or of your judgment to be determined by experience.

If it never becomes necessary to build the siphon between Manhattan and Brooklyn and carry the sewage to a distant point for disposal, the stage of construction which the Commission is now preparing to recommend and which it is hoped you will approve of can be left as the completed work.

Very sincerely,
(Signed) George A. Soper,
President.

March 20, 1914.

Metropolitan Sewerage Commission of New York,
Dr. George A. Soper, President,
17 Battery Place, New York City.

Dear Sir: Your letter of March 13 is received. Referring in the same to my report to your Commission of last November and stating that since then some opinions and projects relating to the sewage disposal have been altered by the Commission in the preparation of its final report, you desire to bring these changes to my attention and ask my opinion in regard to them.

First: Your Commission considers that a restriction as to the dissolved oxygen in the standard of cleanness is not necessary, because, if other standard provisions are complied with, there will be sufficient oxygen in the water to answer the requirements. You, therefore, omit the specific restriction.

I am fully in accord with this opinion, for I believe it would not only be impracticable to maintain a uniform minimum standard for all parts of the harbor water at all times, but the securing of other conditions, which are more readily appreciated by the population, such as the elimination of floating matter and sludge deposits, will of themselves leave sufficient oxygen in solution for all reasonable requirements.

Secondly: With reference to the relief of the Lower East river, your Commission applies the principle of gradual construction and recommends the taking in hand at first the building of certain intercepting sewers along the Lower East river both in Manhattan and in Brooklyn, and the location of certain pumping stations with screens at the most available points, discharging the sewage well out from shore at the bottom of the river through multiple outlets to insure immediate and thorough diffusion. Your Commission further states that when the Ocean Island and outlet will be required no part of the above construction will have to be discarded except the submerged outfalls.

Also with this modification of your views of last autumn I am substantially in accord.

In order to increase the dissolved oxygen in the harbor waters, it is my opinion that not only the floating matter, but also the sludge, should be retained on land as far as practicable, or it should be prevented by suction dredging from accumulating anywhere in the harbor.

Regarding the exact detailed location of the marginal sewers and of the submerged outlets, they will naturally depend entirely upon local surveys, studies and estimates of cost. In general, it is my impression that the outfalls and their provisional positions have been carefully selected. Although these detailed investigations may indicate some changes or additions, the principle of your proposed treatment to greatly reduce the present number of outfalls and extend the discharge points well out into the current is, in my opinion, the best solution of the problem.

Very truly yours,
(Signed) RUDOLPH HERING.

SECTION V

REPORT OF GEORGE E. DATESMAN, C. E.

TO THE PRESIDENT AND MEMBERS OF
THE METROPOLITAN SEWERAGE COMMISSION OF NEW YORK.

GENTLEMEN: In accordance with a request of your President that an examination be made of the conditions existing in the Lower Hudson, Lower East river and Bay division of New York City and comparisons be made of the projects for the treatment of this section, together with suggestions or recommendations relative thereto, I have the honor herewith to submit a report.

The inspections made, both on the occasion of a recent visit, covering several days, and upon previous occasions, were confined to the banks of the Lower East river.

They were made with a view of reporting upon the most suitable means of collecting the sewage along the river front and the merits of locally placed settling tanks as compared with screening stations. Various alternative projects originating with the Commission or with others for the treatment and disposal of the sewage tributary to the Lower East river were considered.

PRESENT CONDITIONS

The Lower Hudson, Lower East river and Bay division comprises the most populous portion of the Boroughs of Manhattan and Brooklyn. An inspection shows that the conditions along the Lower East river south of Blackwell's Island make it difficult to deal with this portion successfully. The area contributing the sewage includes a great number of high buildings, with density of population. Within its boundaries are some extensive docks, upon which are handled much of the commerce of the port. Much land, originally marsh, along the banks has been reclaimed by the building of bulkheads and filling. Land values, exclusive of the lofts and office buildings which crowd thickly in this area, are higer than in any other part of the city, except toward the central ridge of the Borough of Manhattan. Existing and proposed subways have an important bearing upon the drainage problems.

The Lower East river is subject to tidal flow both from the Upper bay and from Long Island sound, which, while giving rise to currents of scouring velocity, do not supply sufficient flow either from the bay or sound to replace daily the water that composes the tidal prism, much less the volume beneath the level of mean low water.

Sewers which discharge at the bulkhead line into the docks and at the ends of piers into this portion of the river contribute an amount of putrescible matter which, flowing backward and forward with the tide, is not sufficiently diffused to hide the sewage and grease which deposit in the slips between the docks and elsewhere, creating nuisance. The discharge of large volumes of sewage with its suspended solids tends to silt up the harbor and in places requires expensive dredging.

From the progress reports of your Commision it appears that the amount of water displaced at each ebb tide is but one-eighth of the volume of the Lower East river below low water; that the ratio of the sewage (contributed from a population of upwards of 2,000,000 at present) to the volume of water beneath the level of mean low tide is but 1 to 244; that the ratio of this sewage to the tidal prism is but 1 to 32.3; that the ratio of this sewage to the ebb flow is but 1 to 5.9, and that the average dissolved oxygen content available for oxidation of the organic matter in the sewage is less than 50 per cent.

FUTURE CONDITIONS

The conditions at present, being such as to cause nuisance to sight and smell and a possible menace to the public health, will unquestionably become accentuated in the future.

The works projected by the Commission for the improvement of the Harlem section provide for the ultimate collection of about 400 million gallons per day of sewage to the upper end of Ward's Island, where it will be treated in grit chambers and settling tanks and discharged through submerged outlets into Hell Gate.

A collecting system for the disposal of the sewage of Newark, Passaic and other cities in the Passaic Valley and its discharge in the Upper bay at Robbins Reef is under construction by the Passaic Valley Sewerage Commissioners.

From float experiments made by your Commission in the Upper bay and in the East river, it is apparent that with the ebb and flow of the tide the effluent which will have to be disposed of by dilution at Robbins Reef and also that from the Ward's Island disposal plant will add to the pollution of the Lower East river. Account should also be taken of the increasing quantity of sewage from the Manhattan and Brooklyn shores.

It is reasonable to suppose that by 1940 there will be an increase in commerce, in the number of high buildings and density of population, resulting in an increase in sewage pollution, without any change in currents or volume of flow in the river which will increase its diluting power.

From calculations published in your progress reports it appears that the ratio of sewage to diluting water in the East river in 1940, provided this sewage is discharged therein, will be as follows:

Sewage to volume below low water	1 to 132
Sewage to tidal prism	1 to 17.5
Sewage to ebb flow	1 to 3.2

Comparison With Other Cities

The City of New York is fortunate in that it is situated upon one of the finest natural harbors of the world, and this, undoubtedly, is its greatest resource. The city cannot with impunity neglect the conservation of this resource or fail to provide its population with surroundings as healthful as modern science will admit.

The discharge of the wastes of the city into the harbor is a prodigal waste, for this practice discourages commerce and is in sharp contrast to the care with which other large cities guard their harbors.

Boston has taken the initiative in the matter of sewage disposal, having cleaned up its waterfront and carried its sewage a considerable distance to sea. Whether or not this method of disposal will always be regarded as efficient, it clears the way for the expenditure of large sums upon its dock system which will no doubt bring results.

Baltimore is about completing an extensive system of sewage collection and disposal and is largely increasing its dock facilities.

Philadelphia is awake to the necessity of providing more adequate means of sewage disposal than exist at present. It is adding largely to its dock system and is a competitor for the commerce which comes to this side of the Atlantic.

European harbor cities, without exception, have considered the construction of adequate sewage collection and disposal systems essential in connection with their dock improvements, and have therefore constructed them.

Governing Factors for Final Disposal

In a consideration of the question of the final disposal of the sewage of the Lower East river, the essential features are, in my opinion, as follows:

1. The removal of sufficient of the solids and putrescible matter to admit of the river maintaining itself free from nuisance to sight, to smell and to the public health.

2. Commercial requirements include the removal of floating matter from the sight of those using the harbor and the prevention of undue deposits of sewage origin or of grit which would silt up the harbor.

3. The system determined upon must impose the least damage to any locality with consequent depreciation of the surrounding territory. There should be the least amount of nuisance or objectionable conditions created in special localities.

4. The waters which flow out of the East river should not be so polluted as to cause unsatisfactory conditions along the banks of the Upper bay, thereby retarding development in such sections or causing depreciation in property to the detriment of the municipality and individuals.

5. There should be the lowest construction cost consistent with the improvement needed.

6. There should be the lowest maintenance cost.

7. The system should be so arranged as to furnish convenient means of organizing the operating force.

8. There should be adopted a system of collection from the mouths of the present combined sewers which will not create unsatisfactory conditions in the contributing sewers.

9. This system should minimize the necessity for accessories which are difficult to operate and maintain.

10. The works should provide for collectors which will promptly carry the sewage to the points of treatment.

Methods of Treatment Studied by the Commission

Various methods of treating the sewage of this section of the city have been studied by the Commission, among which may be mentioned the following:

1. Submerged outlets at various points along the river.
2. "Floatation chambers."
3. Grit chambers and screening stations.
4. Land treatment.
5. Percolating filters and tanks.
6. Locally placed tanks.
7. Removal of the sewage from the Lower East river section and discharge into the Upper bay.
8. Removal of the sewage to an island at sea.

1. SUBMERGED OUTLETS

By this plan the sewage would be collected by means of marginal sewers from the mouths of the existing sewer outlets to convenient points along both banks of the river and discharged by submerged outlets into the channel.

A comprehensive examination of the river channels, including that of the Lower East river, made by your Commission, has revealed the fact that the amount of pollution due to sludge deposits on the bottom is considerable, this condition being most pronounced in the docks and along shores.

The disposal of raw sewage under water is favorable to dispersion, but it also favors the deposit of sludge into eddies and docks and along mud flats.

Examinations along the Manhattan shore of the Lower East river at the mouths of the existing sewers have shown that the sewage, not being as saline as the harbor water, was not readily mixed with the salt water of the river, in consequence of which it remained turbid and undiffused for long distances. This, however, did not prevent the deposit of solid, gritty and putrescible matter. Therefore, if the sewage received no other treatment than discharge through submerged outfalls, there would be no lessening of the amount of material that would be deposited and the amount would increase with the passage of years.

It has been suggested that when these sludge deposits form, even though they may not become a nuisance by reason of the depth of water over them, they may be removed by dredging when concentrated in the bottom of the river. Sludge is the most difficult material to dispose of in connection with a sewage disposal plant, and it is much more difficult and expensive to remove when scattered over many square miles of river bottom.

Such deposits would injure the navigable channels of the harbor. The constant disturbance of these deposits by vessels and the removal of the accumulations by dredging would be detrimental to commerce and would probably cause more nuisance than the present method of disposal.

2. FLOATATION CHAMBERS

Floatation chambers, so-called, would consist of enlargements of the mouths of existing sewers with properly arranged baffles and sumps to admit of the deposit of the grit and the skimming off, by suitable devices, of the floating solids.

When it is considered that with this scheme the sewers would be subjected to fluctuation in velocity due to changes in the tidal level, it is difficult to see how there would be a sufficiently uniform removal of either grit or floating solids to constitute a satisfactory treatment. Furthermore, the putrescible matter which would be added to the river would be but slightly lessened in amount. Therefore, floatation chambers should not be considered as an adequate system of final disposal.

3. GRIT CHAMBERS WITH SCREENS

It has been considered that a sufficient treatment of the sewage might be accomplished by establishing screening stations at intervals along the shores, each station to contain grit chambers to which the sewage would be led by interceptors and pumps to discharge the effluent through submerged outlets into the East river.

Some examples of European cities may be cited as precedents for this plan. Among the German cities which have maintained for some time and are successfully treating their sewage by means of grit chambers and screens, may be mentioned Hamburg, Frankfort a/Main, Düsseldorf and Dresden.

At Hamburg the collecting system is so arranged that none of the sewage escapes by overflows directly into the harbor except when diluted with at least four times its volume of storm water. The Elbe differs from the harbor conditions at New York in that the tidal range is about 19 feet and in the fact that it is fresh water. Therefore, there is a greater diluting volume and a more intimate admixture of the sewage effluent with the harbor water than would be the case in New York. In the other cities, one upon the Elbe, another upon the Main and another upon the Rhein, the conditions are similar to those at Hamburg as to the character of the water, though there is no tide.

The dilution at Dresden is much greater than the dilution possible in the Lower East river calculated on the basis of the tidal prism. The dilution at Frankfort on the Main at times of low stages due to lack of rain is 1 in 30; at mid-stage 1 in 1,000; high-stage, 1 in 3,000. At Düsseldorf it is 1 in 1,000 at low stages of the river.

One of the advantages which is claimed for screening stations is that they require but little land and therefore would result in great saving over larger though more efficient works.

In considering the advantage to be gained by the installation of screening stations over the conditions which now exist, it may be stated that the efficiency of screens varies from 10 to 60 per cent. in the removal of suspended matter. In the investigation made by your Commission, it was found that the effectiveness of screens was about 20 to 25 per cent.

It has been shown that the solids removed by screens are largely non-putrescible, and it is doubtful whether the resulting benefit to the river into which disposal is made will be more than one-half the above-mentioned percentages. Although probably of considerable use in other parts of the city, I do not think the benefit to be gained by screening will admit of this process being accepted as a final and effective method of disposal for the Lower East river section.

4. LAND TREATMENT

The possibilities of land treatment for the sewage of New York are admirably dealt with in the progress reports of your Commission. There is unquestionably not sufficient land available within reasonable distance to admit of such a system as is in use in Berlin and Paris. Land treatment for large cities in England has in nearly every case been abandoned, not only because of the large areas required and the expense, but because of the objectionable conditions, approaching nuisance, which have arisen in connection with them.

5. PERCOLATING FILTERS

Percolating filters as a means of oxidizing sewage and obtaining an effluent that is non-putrescible and therefore fit to be discharged into a stream without nuisance afford one of the most rapid and effective methods of sewage treatment known.

In the matter of precedent, we have the treatment of 30 million gallons per day in Birmingham, England; 6½ million gallons in Wilmersdorf near Berlin, Germany; 12½ million gallons in Columbus, Ohio; 22 million gallons provided for in Baltimore, Md., and various smaller plants throughout this country and especially in England.

While this treatment would doubtless afford adequate protection to the Lower East river, there is no precedent for a single plant or group of plants that would take care of 200 million gallons a day and upward. They certainly should not be located in the occupied portion of the city.

The City of Philadelphia is making careful studies of the advisability of installing percolating filters to take care of the sewage of the entire city, exceeding three-quarters of a billion gallons, but in the absence of information to indicate how much nuisance from odors and flies would be created by this vast area of percolating filters, it is questionable whether the scheme will actually be carried out. If, as is done in some American plants, two million gallons daily can be treated upon one acre, it would require no less than 100 acres of filter beds to treat the sewage from the Lower East river section.

One of the progress reports of your Commision indicates that there is no suitable land within a reasonable distance of New York City which can be obtained at a cheap enough figure to make treatment by filters economical. Unquestionably they would produce an inadmissible nuisance if constructed within the built-up sections of the city.

6. LOCALLY PLACED TANKS

The plan of treating the sewage of the Lower East river in settling tanks concentrated at one point would be open to the same objection, lack of available land, as that mentioned for percolating filters.

The idea of locating settling tanks along the shores of the river at suitable places, either under the surface of the streets or on purchased property near the marginal avenues, has received careful consideration from your Commission. The sewage, brought to the works by a system of interceptors, would be passed through the tanks for a suitable period of time, say two hours, so as to admit of the deposition of the heavier suspended solids and a part of the putrescible matter.

The results of my studies and observations in Europe and America compare favorably with the deductions as to the comparative efficiency of screens and settling basins published by your Commission.

If a tank of proper design would remove in two hours 60 per cent. of the solids capable of settlement, or 50 per cent. of the total solids, it does not follow that the putrescible matter which produces nuisances would be reduced in the same proportion. Rather less than one-half this reduction, or 20 to 25 per cent., is the most that can be expected in the reduction of the organic matter, which is the material which has an avidity for oxygen and tends to its depletion.

Tank treatment does not result in a removal of much of the discoloring property of sewage. Consequently, even with the best practicable admixture with harbor water, by means of submerged outlets, the presence of the sewage in the water might be detectable by sight.

During storms the increased quantity of sewage would necessarily decrease the settling period and consequently increase the amount of solids discharged into the river with a consequent effect upon its color and turbidity. Tank treatment, therefore, where applicable, would be more effective than screens.

Following is a concise statement of the main argument for and against locally placed settling basins of various types as applied to the Lower East river conditions.

a. Tanks Placed Under Streets Along the Lower East River.

Tanks placed under the streets would possess the following advantages and disadvantages:

Advantages. The number of tanks needed could be adjusted to the requirements of the existing sewer outlets. They would effect a saving in the cost of interceptors. They would afford a convenient means of disposing of sludge, since this could be done by pumping to a barge which would carry it to sea.

Disadvantages. There would be many difficulties of construction. There would be danger from confining the gases of putrefaction, giving rise to the possibility of explosions and injury to adjacent buildings. The operation would be difficult, owing to the organization being divided into many units. Proper inspection of the workings of the plants would be difficult—a matter of much importance—since settling basins must be operated properly in order to avoid nuisance. There might be danger to the health of the employees working under these unfavorable operating conditions. There would be real or supposed damage to property and probably legal injunctions against the plant in case of nuisance. There would be difficulty in sinking the caissons for the proper construction of the tanks in land adjacent to the river, with the possibility of upward pressure distorting them. There would be much interference with traffic during construction and some risk of interference with same when in operation.

b. Tanks Located on Property Adjacent to Streets for Treatment of the Combined Flow of Several Sewers.

Advantages. As compared with a plan to take the sewage to a distant plant for disposal, ability to treat the sewage near the point of production. Saving in the cost of siphons, along outfall, conduits built as tunnels and expensive terminal works. Saving in the amount and cost of pumping by taking advantage of daily low tide for discharge of effluent in part without pumping.

Disadvantages. Owing to the occupation of all the land by buildings on both the Manhattan and Brooklyn shores, the cost of obtaining land at points near the river would be great. The land upon the Manhattan side is valued at from $200 to $500 per front foot of 100 feet depth. On the Brooklyn side it is valued at from $100 to $200. The area required for tankage to treat 20 to 25 million gallons of sewage per day is 100 by 300 feet, and to dispose of the dry-weather flow alone, amounting to upwards of 200 million gallons per day, would require no less than from 8 to 10 such units. There would have to be added to this the cost of the buildings which might happen to be on the various sites; these buildings would have to be purchased and removed. It would be impossible to utilize the land over the tanks for the construction of buildings because of popular prejudice, if not for reasons of health. There would be a deterioration of the surrounding property resulting from real or supposed nuisance created by occasional uncontrollable conditions of operation.

c. Tanks Removed Several Blocks from the River.

The same advantages and disadvantages would apply to tanks located some distance inland as to tanks placed near the river front, and there would be the added disadvantage of greater difficulty in disposing of the sludge. Sludge storage tanks would have to be provided; sludge mains would have to be laid; there would be need of additional conduits to carry the effluent from the tanks to the point of final disposal and there would be much interference with traffic during the construction of the works and the rearrangement of the underground structures.

TYPES OF TANKS

A. Emscher Tanks

Advantages. Ability, when properly operated, to avoid nuisance due to odors. Facility with which the sludge can be cleaned out. Reduction in the quantity of sludge produced.

Disadvantages. Difficulty of building the tanks under New York conditions. The space required: If placed in line they would take up an area of 40 feet by 340 feet for the treatment of 12 million gallons per day. At this rate Emscher tanks would require, for the total output of 203 million gallons per day, no less than 20 plants, aggregating more than a mile in length. There is no precedent for the construction of such tanks under these conditions. There would be great difficulty in removing the sludge from the tanks in the closely built-up sections of the city. Danger of confining the gases generated under street surface, resulting in possible fire risk and explosion and injurious effect upon employees.

B. Dortmund Tanks

Advantages. Practically the same as with Emscher tanks, except that there would be more odors produced.

Disadvantages. The same as with Emscher tanks, except that the depth, difficulty and cost of construction would not be so great and the resulting volume of sludge much greater.

C. Plain Sedimentation Tanks

Advantages. As compared with the preceding, they are nil.

Disadvantages. Impossibility of cleaning out the sludge without removing the supernatant liquor. Nuisance created while sludging. If operated with chemicals, the difficulty in storing, handling and applying the chemicals. Increase in amount of sludge and putrid condition of the chemical sludge.

D. Tanks Subject to Tidal Influence

Advantages. Saving due to lack of necessity for pumping.

Disadvantages. Inability to secure uniform flow and consequently uncertain percentage of solids removed and fluctuation in quality of effluent. Inefficient operation during periods of very high tide. Probability of silt deposits forming in the collectors at high tide. Inability in case of injunction to change or utilize any part of the tank system should the sewage be ultimately carried to distant points for disposal.

The use of submerged outlets, which in German cities is considered essential for proper dilution, is an accessory that should be considered in connection with all these methods of disposal.

Opinion Upon Tank Treatment. The cost of effecting a disposal of the sewage of the Lower East river section by means of tanks locally placed, at the point of receipt of the sewage, would undoubtedly be less expensive, notwithstanding heavy land purchases, than the cost of any plan to carry the sewage a considerable distance away.

Studies made in Philadelphia for tanks placed under the surface of the streets established the fact that while this principle may be applied in isolated cases, it is not generally applicable because of the large space required. In some cases nests of 25 tanks would take up the space under the streets for two blocks and extend over into the cross streets, introducing into the construction and operation so many untried and uncertain factors that, upon this ground, and that of expense as compared with the benefit to be gained, the project will not be recommended.

It is inadvisable to place settling basins beneath the streets of New York because of the weight of the disadvantages over the advantages named and for the reason that the small benefit that would accrue to the river over present conditions is negligible. It is worth noting, also, that there would be a lessening of the benefit to be derived with the passage of time.

There is no precedent for an installation of settling basins of the size required. The experience with tanks, though satisfactory as at Frankfort-on-the-Main, Birmingham, Manchester, London and elsewhere in England, does not, in my opinion, justify the discharge of the sewage from such a plant into this section of the harbor. The amount of dilution is comparable with Birmingham and Manchester only, due allowance being made for the different action of sewage whether discharged into fresh or salt water.

It is therefore concluded by me that while the benefit to be obtained from locally placed settling basins would be considerable, it would not be sufficient. Furthermore, this plan would not lend itself to the development of any scheme for carrying the sewage to a distant point for disposal, so that, should such a development be later found advisable, the sums expended for the settling basins would be wasted.

Treatment by passing through tanks on the lower end of Blackwells Island in the East river is open to the same objections in regard to the pollution of the Lower East river as exist in regard to tanks locally placed, although it would have the advantage of less cost for the necessary land upon which to erect the plant. This advantage would be largely offset by the cost of the siphons to the island.

7. REMOVAL OF THE SEWAGE TO THE UPPER BAY

From progress reports issued by your Commission, it appears that a study has been made to carry the sewage to some point in the Upper New York bay where the diluting water is of such volume as to give a smaller ratio of sewage to diluting water than would occur in any other part of the inner harbor. The proposition would be to construct an artificial island immediately south of Governors Island and, after treating the sewage in tanks, discharge the effluent by submerged outlets into the main channel of the bay.

This plan would have the advantage over locally placed tanks of eliminating the high cost of the land required for the tanks and it would avoid the necessity of destroying the existing buildings and of depreciating surrounding property in valuable sections of Manhattan and Brooklyn. In addition, it would accomplish the entire removal from the Lower East river of the polluting sewage which now empties therein. It would prevent sewage material and deposits of sludge from collecting and lying stagnant in the docks with the consequent nuisance to the public and to the commercial interests. It would also have the advantage of a concentrated operating organization.

An outlet island in the Upper bay would have the disadvantage of being difficult and costly to construct and would present a menace to the cleanliness of the water in the Lower East river, due to a tidal flow which would carry the effluent from the island in that direction. This condition would cause pollution and turbidity of the Lower East river water in addition to that which would be introduced therein by reason of the discharge from the works at Wards Island to the north and from the Passaic Valley sewer at Robbins Reef to the south.

Another disadvantage, and one of no mean proportions, would be in the creation of a popular prejudice against the development upon a high plane of that portion of the Boroughs of Brooklyn and Richmond which lies to the east and south of the site of the works. This might result in a great depreciation of land values and, by reason of an occasional concentration of the effluent from the sewage works, become a source of nuisance to future inhabitants of this territory, resulting in stagnating the growth of these portions of the city. It might become a matter of policy, due to increase in population and of the amount of sewage furnished to the Wards Island works, to carry a certain proportion of the sewage which would ultimately be collected at Wards Island to the island below Governors Island for disposal. If this were done there would be a cumulative objection against this point of disposal.

In addition, such unsettled materials as might be discharged with the effluent might aid in silting up the channel, requiring costly dredging.

Furthermore, the turbidity of the water in the Upper bay would be such as to afford ground for unfavorable comment, on the part of persons on incoming and outgoing vessels and among those who cross the harbor daily, as to the sanitary facilities provided by New York. The works themselves might not be free from objectionable characteristics. It therefore appears that by this scheme the city would be unable to rid itself of the visible presence of sewage and the odors arising therefrom.

The cost of works of this kind would be materially less than some of those proposed, comparing favorably on this score with the scheme for locally placed tanks, but it would be much greater than the latter in the betterment which would be afforded to the Lower East river.

8. REMOVAL OF THE SEWAGE TO AN ISLAND AT SEA

In comparing the studies for the various methods, there appears to be an advantage in removing the sewage a long distance from the point of production.

I am strongly impressed that it is desirable to carry the sewage to a point where the disadvantages which apply to the Governor's Island site can be eliminated, because this would protect the interests of all localities of the city in the matter of real estate development and, for all time, remove, without possibility of pollution, all the sewage from the concentrated area adjacent to the Lower East river, thereby relieving this river and contiguous parts of the harbor of the burden of oxidizing the sewage.

The amounts of sewage effluent which would be discharged at Ward's Island and at Robbins Reef are reasonably well known, therefore it should not be difficult to insure for this portion of the harbor a dilution which would be sufficient to avoid nuisance, turbidity, greasy slime or the deposit of such silt as may come from the streets.

The advantage of carrying the Lower East river sewage to a distant point for disposal is that all the objectionable features, except that of expense, which are apparent against the various other schemes mentioned separately or collectively, would be eliminated. The cost should not prevent the accomplishment of the desired object.

The relation which the City of New York bears to the other cities of the world is unique. Its growth has been so rapid that it is not unreasonable to predict that even at the time provided for by your Commission, namely, 1940 to 1950, it will be the leading city in the world in wealth and population.

As other cities with great harbors have recognized the importance of a sanitary treatment of their sewage as the one essential accompanying the construction of a great dock system, it is apparent that the City of New York, to maintain its commercial and metropolitan leadership, must not be satisfied with any scheme of sewage disposal, the success of which is doubtful.

The difference in expense between a plan of sewage disposal which is experimental or temporary and one which can confidently be expected to be satisfactory should not be controlling when works are contemplated which are to last through the present century.

THE COMMISSION'S PROJECT

Your Commission, after a careful study of details and a comparison of existing conditions elsewhere, has arranged a comprehensive scheme which is well adapted to the situation. Although collectively monumental, there is ample precedent for each part.

Briefly, this scheme consists of carrying the sewage, which now collects and deposits in the docks, to convenient points along the marginal avenues and then conveying it by deep collectors and an inverted siphon under the Lower East river to some point upon the Brooklyn side, where it would be pumped through a conduit built in tunnel through the high land of southwestern Brooklyn under Coney Island and the sea to an island about 3½ miles off the shore. The total length of the conduit beyond the pumping station would be about 13 miles.

The construction of interceptors to collect the sewage from the sewerage systems which now pollute the river fronts is a standard practice both in American and European cities.

The building of the deep conduits and the siphon under the river have their precedents in the remarkable success which has heretofore been achieved in the City of New York in the matter of tunnel construction over that of any other city in the world. The improvement in tunneling machinery, by reason of the impetus given it, will facilitate such construction and enable engineers to estimate very closely upon the length of time required and cost of construction.

The design of recent pumping machinery is undergoing some revolutionary changes. The use of oil for fuel has cheapened this work and recently there has been installed pumps upon the explosion principle which show great economies.

It is reasonable to suppose that even greater improvements will be made within the next few years, so that the matter of pumping 200 million gallons of sewage daily will be accomplished at a comparatively low cost and with no great difficulty.

The site for the proposed island has been chosen upon a natural reef flanked on all sides by deep channels and ocean currents. As the reef has withstood the storms of many years and, from information obtained, has remained unchanged for the greater part of a century, conclusive proof is afforded that the foundation for the proposed island will be durable.

Disposal at this location has all the advantages which have been mentioned for the other schemes, individually and collectively, except as to expense. In addition, it entirely avoids danger of nuisance and depreciation of any of the property within Greater New York, as far as the sewage from the Lower East river is concerned.

Float experiments, carried on over a whole season, indicate unquestionably that the effluent which would be discharged at this island would never reach the entrance to the Narrows nor menace the pleasure beaches at Coney Island and Rockaway.

For the construction of this sea island there is no precedent in sewage disposal works. Similar constructions, however, have been made in New York, and many permanent structures have been erected in connection with harbors and fortifications in other cities of the world having open harbors. The methods to be applied are well known and do not present any insurmountable difficulties. The island would be as capable of resisting the onslaughts of storms from the open ocean as would a breakwater at the mouth of a harbor.

The system of treatment, after the sewage reaches the island, would be by means of settling tanks, the grit and large solids having been extracted in grit chambers and screens at the pumping stations or, if desired, elsewhere along the line of the main collecting sewers.

The discharge of the effluent from settling tanks through submerged outlets into the waters about the island would be favorable for diffusion at all stages of the tide. The currents would serve to distribute it and to increase the diluting volume.

The disposition of the sludge would be simple. The proximity of the open ocean would enable sludge steamers to carry it to sea, finding there such a dumping ground as would prevent the return of any material to the shores.

The Principle of Gradual Construction

The island scheme is flexible and extensible and I agree that it should be carried out in progressive stages. Should the amount of sewage which ultimately reaches Wards Island be such as to cause undue turbidity in the waters of the Lower East river or along Long Island Sound, it would be practicable to carry the sewage by tunnel from Wards Island to the junction with the proposed outlet tunnel or to construct a duplicate tunnel to the island for the disposition of this sewage.

Progressive Steps. The island plan of disposal lends itself readily to progressive construction and the steps which you have indicated appear to me to be the proper ones to take. The first step should consist of the construction of the interceptors, which are essential in any case. The sewage, until such time as the East river becomes overtaxed, should be collected at one or more suitable stations upon both shores of the East river, passed through screening stations and pumped through multiple submerged outlets. This would relieve the worst of the present insanitary conditions.

Precedent for the operation of screening stations for a population equal to that to be served in this portion of New York City without nuisance exists in the city of Hamburg, Germany, where there is placed upon a marginal avenue corresponding with West street, adjacent to docks corresponding to those of the East river and immediately across the avenue from the State Nautical School, a screening station for a population of about 800,000 and another station for 200,000 in the midst of the warehouse district.

Inasmuch as the water of the East river, as regards dissolved oxygen, would not be appreciably improved, I am of opinion that this treatment would be warranted for a time only, or during the construction of the deep, connecting interceptors and the siphon under the river, together with the deep tunnel to the site of the island, or until such time as the extent of the relief required in the Lower East river was recognized as greater than could possibly be afforded by the use of screen stations.

The submerged outlets could be abandoned, or even the screen stations could be eliminated with comparatively little loss, in view of the small area required for the latter and the ability to utilize the pumps in the pumping station to be located elsewhere. It is readily seen that the project of establishing screening stations lends itself as a step in the accomplishment of the greater scheme.

The next step would be to combine the Manhattan and Brooklyn sewage by siphon and pump it to sea, discharging it through a crib* freely into the waters of the ocean. The crib construction could be used as the nucleus about which the island would be built later.

The third step would be the construction of the island and the building of the settling tanks with submerged outlets for the effluent.

Should it be practicable to accomplish the results aimed at both in the removal of the sewage from the Lower East river and the prevention of the return of sewage matter to the shores adjacent to New York City by the crib project without the use of the island, the construction of the island might be indefinitely delayed.

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*This step is not recommended by the Commission. For details of proposed plan, see Part II, Chap. VI, p. 99.

With the foregoing principles and plans of your Commission I am in full agreement. All the essential features are in accordance with well-established engineering practice.

Precedent for Removal of Sewage to a Distance for Treatment

There is ample precedent for the removal of sewage to a considerable distance for disposal, as the following examples show:

Berlin. In the city of Berlin there have been established twelve pumping districts, to each of which a certain proportion of the sewage of the city is conducted, and from which the sewage is pumped to works consisting of irrigation farms, through force mains, in a number of cases 10 miles long and in two cases 15 miles long. One of the twelve pumping stations has a daily capacity of about 75½ million gallons. Several of the larger pumping stations collectively have a capacity greater than that required for the Lower East river sewage.

Paris. The whole of the drainage of Paris is prevented from reaching the Seine within the city limits by means of interceptors and is carried through an outfall conduit to a distance of 17 miles from the westerly boundery of the city. The sewage is applied to sewage farms. It is anticipated that within the near future a more modern method of sewage disposal will be projected and later installed.

London. The sewage of London is intercepted by high-level interceptors, where practicable, and carried by gravity to works at Barking, situated on the north side of the Thames, a distance of 12½ miles from the center of the city. On the south side it is collected at Crossness, 14 miles from the center of the city.

Other interceptors along the Thames collect the low-level sewage and this is pumped to the high-level interceptors. This system has been successful in removing the pollution formerly existing along the banks and in the docks of the harbor, making conditions about the parliament and other public buildings objectionable.

The treatment of the sewage is by tankage, chemical precipitation and discharge during ebb tide.

Philadelphia. The project for the collection of the sewage from the extensive area within the City of Philadelphia includes, as far as decided upon, the carrying of the sewage to two points for disposal. The more remote of these will require the construction of collectors, which, with the contributing sewers, will cause the sewage to travel 12 miles.

Features of Design

The methods available for collecting the sewage from the Lower East river section of the division under discussion are various. The use of collecting sewers is essential and their locations and types are matters to which you have given much study. You have prepared many alternative projects, including interceptors at high and low levels, near and remote from the waterfront, deep-lying and near the surface of the ground and with and without regulators and tide-gates. It is unnecessary to describe these plans here, but I will discuss the topic of collectors from my own point of view.

The highest efficiency in any collecting system is accomplished when the minimum of pumping is required, both as to quantity and lift.

The choice between a high-level system, which would avoid pumping, and a low-level system, requiring pumping, or a combination of both, is made upon the well-known rule that pumping should be avoided wherever possible, even at the sacrifice of some of the results which are desirable.

Where, by reason of the advisability of rebuilding sewers on the separate plan within the area served by a low-level intercepting system, the use of the high-level system is thought inadvisable, there is usually some practicable mean where the low level may be in part converted to a high level, thereby lessening the amount of pumping required and the area over which it is necessary to rebuild the system.

In my examination of the collecting systems I was impressed by the fact that, especially in the German cities, the interceptors had been planned and were operating more economically than is the case in the usual American city. In fact, I know of no case in this country where the same principles have been followed.

High- and Low-Level Interceptors

It might be proposed to carry a high-level interceptor by deep tunnel close to the ridge of Manhattan Borough and a similar sewer a considerable distance away from the river upon the Brooklyn side. The advantage would be that these interceptors could be built without interfering with traffic, subways or underground structures. Owing to the fact that a majority of the sewers in the areas of lower Manhattan and Brooklyn are subject to tidal influence for a considerable distance from their outlets, the construction of such high-level interceptors would leave extensive areas in which there probably would be required the reconstruction of existing storm sewers and the addition of the sewers which would collect the house drainage to low points, where it could be pumped into the high-level interceptors.

The difficulty of the latter construction, due to interference with traffic, the network of underground structures, the cutting up of the district by proposed subways and the cost of requiring alterations in the plumbing of many houses, added to the large cost of repaving the streets, would appear to make the approval of this proposition inadvisable.

The placing of interceptors along the marginal avenues crossing under the inverts of the existing outlet sewers would avoid reconstruction and the introduction of the double system of sewers in a large territory, but would be attended with the difficulty found in deep foundation work and would probably require the use of compressed air at considerable cost. It would add to the pumping cost and maintenance, would require the use of regulators and tide-gates, all of which are more or less unreliable in their action, and would require constant maintenance.

Connections With Interceptors

A method of designing interceptors, which may be discussed in relation to the New York project, is the system which has been practiced in most of the European cities, notably those in Germany, consisting of a conduit across the mouths of the existing outlets entirely excluding the sewage collected therein from the harbors or streams.

This system has the disadvantage of requiring larger cross-sections for the sewers, but, on the other hand, the increased size, allowing flatter grades, would save in the depth to which the construction would otherwise be carried.

The system involves placing, at intervals, overflow dams with storm-water conduits to the river so that when the flow is collected from a number of sewers, to which has been added storm water from 3 to 6 times the dry-weather flow, the diluted sewage overflows the dams and reaches the harbor.

The only regulators which would be required under this system are the dams themselves, automatic tide-gates being unnecessary, except as in the case of Hamburg, where, by reason of large tidal range, the sewers are called upon to act as a reservoir for a part of the time.

The elimination of moving part regulators and tide-gates are matters to be carefully weighed, as their use is unreliable and would tend to increase the operating cost and possibly at times overtax the pumping stations.

A system which is a modification of the principles in use abroad, which would admit of considerable saving over the usually applied American system, has been developed in the case of the collectors at Philadelphia.

It has been found economical to build both high- and low-level sewers, carrying every cubic foot of sewage practicable by gravity to the treatment works. In the low-level system, by substituting a dam to exclude tide water in the combined sewer at such a point removed from the outet that the crest will not rise beyond two-thirds of its vertical diameter, large tide-gates at the outlets may be eliminated. Thus to the advantage due to grade in the sewer, saved in the depth of the main collector, is added the advantage of carrying the interceptor through the dam, resulting, in some cases, in raising the whole length of the interceptor from 6 to 10 feet over its position in the usual American plan. This, of course, involves the construction of a system of domestic-sewage sewers in streets tributary to the main combined sewer below the dam and the making of new house connections.

The effect is to leave open to tidal fluctuation that portion of the combined sewer between the dam and oulet. If the sewage is carried away from a river, even the tide-locking of this portion of the sewer should not be a detriment to the intercepting sewers, which are not affected thereby in a pumping system.

The benefit in the item of cost of a long interceptor, by being able to raise it from 6 to 10 feet, is apparent; also the saving due to decreased lift at pumping stations.

Where grades of combined sewers admit, additional savings may be made in depth of interceptors by placing them at some distance from the marginal avenue. This should, however, always permit of a house-sewage sewer, when running against grade, reaching the interceptor.

Another accessory of this plan is the introduction of overflow chambers of enlarged section to admit of carrying off the storm flow into the conduit below, wherever the dams are introduced.

In Philadelphia it has been planned to introduce such dams, even in low-lying areas where tidal influence extends between 4,000 and 8,000 feet from the outlets. The dams will be placed at about 2,500 feet inland from the river, involving the building of a separate system of sewers in the territory below the dams and carrying of the drainage back to the main collector. Light grades may be used on the small sewers, which may be flushed at high tide from the river, either automatically or by hand-operated gates.

Suggestions Applicable to New York

The placing of such interceptors as have been described along the Lower East river in both Manhattan and Brooklyn Boroughs would, in my judgment, result in economies in first cost; would reduce to a minimum the area that would be required to be sewered upon the double system and, if placed generally about two blocks back from the river, would interfere less with the traffic; would admit of the house drainage from the river front being carried backward for these two blocks into the main interceptors; would gain considerable from the depth, due to the grade of the existing sewers; would proportionately lessen the lift required of the pumps, and would raise the head upon any siphon which would be put in the final scheme for disposal at a distance, thereby lessening the lift for pumping and consequent cost for all time.

As to precedent, it may be mentioned that Hamburg has a tidal range of 5.8 meters. This city, especially along the routes of the main interceptors, is intersected by canals and is, therefore, very flat. Notwithstanding this fact, the interceptors carry across the mouths of the combined sewers, overflows for storm water being secured at convenient intervals by the water rising above the dams fixed to carry to the works several times the dry-weather flow. By means of tide-gates upon storm overflows, the harbor water is excluded, the conduits discharge when the tides are favorable, the system acting as a reservoir when they are unfavorable. Cleansing velocities are obtained at low stages of the tide. As this is a screening system, the fluctuation of flow is not material.

If, therefore, a low-lying city like Hamburg can discharge from combined sewers through collectors whose inverts are below sea level without resorting to pumping, as is the case in the north side station, it may be practicable by study of the New York marginal collectors with a certain amount of reconstruction of the local sewers to accomplish equally good results.

In some cases, at least, pumping may be lessened, especially if the proposed temporary screen stations are installed on the banks of the Lower East river.

While Hamburg is most analogous to New York, with the advantages of topography in favor of the latter, the same general scheme is carried out in other European cities where tidal conditions do not prevail, but where flood water heights in the rivers must be contended with, notably at Leipzig, Dresden, Frankfurt a/Main, Munich, Vienna and Paris.

The types of interceptors are such as to provide proper sectional area in the inverts for dry-weather flow, with additional provision for collecting the storm water from the combined sewers and carrying it to suitable places for discharge. The dams used are placed at about or above the springing line of the interceptors, the flat-section storm conduits discharging without tide-gates in most cases, the invert of the interceptor being under the low-water stages, or, as in the case of Hamburg, under the sea level.

In an examination of the profiles of collectors along the Manhattan and Brooklyn banks of the Lower East river section, as published in Preliminary Report VI of your Commission, it appears to the writer that, notwithstanding the statement that the sewers are in many cases tide-locked at high tide, the elevations of the existing sewer outlets lend themselves to a collecting system similar to that just described. The feasibility of this, however, is dependent upon there being a considerable fall in the tributary outfall sewers toward the river. Should examination prove the practicability of this plan, the interceptors should be built with falls generally as shown upon your diagrams, but at an elevation which would place them directly across or slightly below the mouths of the existing sewers and bring the sewage to the proposed screen stations at such elevations as to permit of discharge through screens with a minimum pumping lift. This of necessity would require storm overflows without tide-gates, in some cases the present outfalls being utilized; in others conduits one or two blocks long being specially constructed.

This system would require a considerably larger cross-section than has been planned, but would avoid tide-gates and would gain possibly one-half of the total depth as planned, thereby admitting of open-cut construction without the use of compressed air tunneling methods. It would be somewhat objectionable on account of interference with traffic.

The tidal circulation through the system would continue the present condition of fluctuating velocities, but this would be compensated for by the saving in cost of smaller pumping stations, especially if they were temporary, and could later be abandoned.

If tidal flow through the collectors is considered inadvisable, sewers of the same sizes as those projected could be placed at elevations possibly one-half the depth of those shown upon your plans, especially if they are placed along avenues, say two blocks from the marginal streets, or about midway between the river and the limit of tidal influence. These sewers could deliver the sewage at an elevation requiring pumping for a portion of each tide only.

But a comparatively small area would require to be supplied with house sewage sewers, say two blocks, the drainage being carried by gravity into the main collectors.

It would also lend itself admirably to the final disposition at the ocean outlet island and would save the capitalized cost of lifting, by pumps, 200 m.g.d. through the number of feet saved in the depth of the interceptor.

The former scheme would require no regulators except overflows, but would not divide the sewage from storm water as well as the latter, until the installation of the pumping station to the island.

Should the latter installation be found feasible it would involve the construction of dams in the storm sewers, with overflow chambers, and regulators to intercept a certain amount of sewage during storms, especially after the introduction of the pumping station to the sea island.

I am, therefore, reasonably sure that a higher low-level collecting sewer than the one you have planned would be feasible, not only for this section, but in other marginal sections, at a great aggregate saving in construction cost. This would, in my opinion, result in a considerable reduction in the capitalized cost of operation, thereby strengthening the argument in favor of your comprehensive scheme of disposal for this division.

Conclusion

After a careful consideration of the various projects discussed in this report for the collection and disposal of the sewage from the Lower East river section, I am of the opinion that the use of collectors is essential for any satisfactory system of disposal.

Locally placed settling tanks as a final means of disposal, while they may be constructed at less cost than the other suggested schemes, would not afford sufficient relief to the Lower East river to make their installation a lasting benefit. This is not intended to discourage their use where the volume of dilution is sufficiently great and the immediate land surroundings are suitable.

If used, the settling tanks should be of a form from which the deposits can be removed without throwing the tank out of service. A Dortmund tank or an Emscher tank would fulfil this requirement.

The use of grit chambers and screening stations, while not as effective as tank treatment, would afford a temporary measure of relief pending the extension of the system, without appreciable loss when the entire project was completed.

Respectfully submitted,

(Sgd.) Geo. E. Datesman.

Philadelphia, January 30, 1914.

CHAPTER II

REPORTS ON SPECIAL TOPICS

SECTION I

RELATION BETWEEN THE DISPOSAL OF THE SEWAGE AND THE DEATH RATE AND A REPORT BY WALTER F. WILLCOX ON THE CRUDE AND CORRECTED DEATH RATES OF NEW YORK, LONDON, BERLIN AND PARIS FOR THE 10 YEARS 1900-1909

Since the system of main drainage proposed by the Commission will eventually cost many millions of dollars, it is desirable that the taxpayers should understand the benefits to accrue from it.

The most important benefit would be to health. The argument upon this head, although circumstantial and incapable of mathematical demonstration, is nevertheless conclusive. It rests upon the known relations which now exist between the polluted condition of the harbor and the public health, as, for example, bathing, shellfish, driftwood, flies and odors and the possibility of materially reducing the death rate through a systematic treatment of the sewage. The relation between the public health and pollution was discussed in the Commission's reports of April, 1910, Part III, Chap. X, and August, 1912, Part II, Chap. I, II and III. The opinion was reached that whereas no definite effect upon the death rate could be ascribed to the polluted state of the harbor, it was impossible to avoid the conclusion that a considerable amount of harm was produced. The present unsatisfactory conditions of sewage disposal and the possibility of reducing the death rate are briefly discussed in this place.

On comparing the death rates of New York with those of London, Paris and Berlin for the last year for which the statistics of all four of these cities are available, it appears that New York's rate was exceeded only by that of Paris. For the 10 years ending in 1909, New York stood at the bottom of the list. London and Berlin were well in the lead. These facts referred both to the crude and corrected death rates, as shown in the following table:

TABLE XXV

Death Rates, 1900-1909

	Crude				Corrected by U. S. Registration Data			
	Average 1900–1909	1900	1909	Decrease	Average 1900–1909	1900	1909	Decrease
London	15.7	18.6	14.0	4.6	15.4	18.2	13.7	4.5
Berlin	16.6	19.0	15.1	3.9	18.0	20.6	16.4	4.2
New York	18.5	20.6	16.0	4.6	20.1	22.5	17.5	5.0
Paris	18.0	19.6	17.2	2.4	18.8	20.5	18.0	2.5

For the purpose of studying the relative healthfulness of cities, corrected death rates are indispensable, since they have for their object the elimination of differences in the population which considerably affect the results. When the corrected death rates of the four cities here mentioned are compared, it is seen that the death rate of New York is higher than the crude rate indicates, whereas the corrected rate for London is lower than the crude rate for that city. Consequently, the difference in healthfulness between London and New York is seen to be greater than the crude death rates indicate. London's crude rate of 14 is 12½ per cent. less than New York's crude rate of 16, and London's corrected rate of 13.7 is over 21 per cent. less than New York's corrected rate of 17.5.

Comparing New York with the other cities in the group, it will be seen that Berlin's corrected rate of 16.4 is 6.3 per cent. lower than the corrected rate for New York. New York's corrected rate is exceeded by that of Paris by 2.8 per cent.

There appears to be no reason why New York should not have as low a death rate as London or Berlin. On the contrary, it can apparently have the lowest rate of any city of its class, and the attainment of this result should be the aim.

New York is a good example of a city of the largest class wherein the highest requirements of sanitation are demanded and are, at the same time, capable of being satisfied. Occupying an unrivaled situation, a favorable climate, good and abundant water supply and an efficient health administration, it should be the aim of every citizen to make New York's death rate the lowest to be found among the municipalities of the class to which this city belongs. New York should be the cleanest city in the world if for no other reason than to afford a barrier against the danger which results from the immense influx of immigrants from all parts of the world who, not infrequently, bring epidemic diseases to this port, a danger which is intensified by the highly congested conditions under which most of the population lives and works.

Owing to the congestion of population, practically all the conditions necessary to maintain life in a wholesome way must be secured through a careful and skillful observance of sanitary rules and principles. This relates not only to the food, clothing and habitations of the people, but, in a peculiar degree, to the care of their wastes. Upon the prompt and complete disposal of these wastes largely depends the comfort, convenience and healthfulness of the city.

The Unsatisfactory Conditions of Sewage Disposal

The history of sanitation shows that the greatest strides of progress have often resulted from great object lessons, such as epidemics, plagues and pestilences which have pointed strikingly to the fact that the problem of disposing of the human wastes was not being properly dealt with. Such sanitary emergencies now rarely occur in the largest centers of population and are no longer to be expected in the city of New York, which possesses an efficient health administration. Sanitation in cities of this class now, and in future, may be expected to progress upon modern scientific and conservative lines. The conditions to be controlled must be discovered and provided for before they result in nuisance and disease. Large schemes for sanitary improvement must be made and made after careful investigation while yet there is time. This is the way in which the new water supply of New York was provided for. No great epidemic or conflagration or drought pointed to its necessity. Competent and far-sighted investigations pointed to its necessity, it was recognized that some years would be required for its construction and the city proceeded to spend $160,000,000 to carry it out.

The most important sanitary provisions which a modern city can possess are the public water supply and sewerage system. The relation between these two public services is very close. Aside from a small proportion of the water which is used for drinking purposes and for the extinguishment of fires, nearly the whole of the public water supply is used for cleansing, that is, for the removal of bodily, household and street wastes.

The sanitary function of water is to act as a vehicle in removing the waste materials from their source. To be satisfactory, this removal should be prompt, complete and unattended by injury to health or offense to the senses. Removal to a certain distance from its points of origin usually can be accomplished satisfactorily up to a certain point by modern sewerage systems, but the disposal of the sewage at the outlets of these systems often presents a problem of great difficulty.

Until recently there has been no question as to the efficiency of the custom of sewage disposal pursued by New York and its neighboring municipalities. House sewage and street washings have been discharged without regulation or purification of any kind into the nearest tide waters. Investigation has shown that it is unwise longer to count blindly upon the purifying action of dangerous and offensive wastes which are discharged every day into the arms of the harbor which intersect the city in every direction. Only a part of the sewage is flushed out to sea; some is turned into gas; some is liquefied by the bacteria in the water, and some is stored in pockets and sludge banks. All of these processes are attended with more or less nuisance. Gradually the harbor as a whole is becoming over-polluted.

Possibility of Reducing the Death Rate

That a material reduction can be made in the death rate seems assured by the reduction which has been made in it during recent years, from the fact that this city does not now possess a large death rate as compared with London or Berlin, and from the fact that such a reduction always follows the introduction of a great sanitary improvement.

New York stands third among the four great cities in regard to its death rate, the crude or uncorrected rates for which are commonly but erroneously assumed to give a correct basis for comparing the relative health of the populations. The crude death rate, which is obtained by multiplying the number of deaths per year by one thousand and dividing by the population gives an imperfect knowledge of the healthfulness of a city, since it fails to take account of well-recognized differences in susceptibility to disease which exist among different elements in the population. Females have lower death rates than males, in consequence of which a city which has an unusually large proportion of males is healthier than it appears to be. Young children and old persons have a higher death rate than the average, from which it follows that a city in which there is an unusually large proportion of persons in middle age is less healthy than it seems.

Among the most important causes of these differences in susceptibility in the greatest cities are those which are due to sex and age. A proper comparison of the healthfulness of cities cannot be made until their crude death rates have been corrected.

In 1913 the Commission requested Prof. Walter F. Willcox, the eminent statistical expert of Cornell University, to report on the corrected death rate of New York City, comparing the age and sex distribution of New York, London, Paris and Berlin with each other through some standard population. Professor Willcox found that in London, Paris, Berlin and New York the females outnumber the males. The difference is least in New York, 4 in 10,000 and greatest in Paris 638 in 10,000. The effect of the correction to be made on this account is to raise the rate for New York.

New York has a larger proportion of persons in the healthy ages than any of the other cities with which it can be compared. Among every 10,000 persons in New York, there are 249 more than there are in London who belong to the healthy ages. The effect of the correction to be made on this account is to lower the rate for New York.

The corrections for sex and age to some extent counterbalance each other. If corrected for sex, New York would have a lower death rate than any of the other three cities; if for age, the rate would be higher. The combined effect is to make the crude death rate lower than it should be. This influence is stronger in New York than in any of the other cities.

REPORT OF WALTER F. WILLCOX

President George A. Soper,

Metropolitan Sewerage Commission of New York.

Sir: You have asked me to report on the corrected death rate of New York City, comparing the sex and age distribution of the population in New York, London, Paris and Berlin through some standard population and showing what influence the differences between the standard population and the population of these cities would have on the death rate of New York City for the decade, 1900-1910.

The first difference to be examined is that in the proportion of the sexes. It is well known that the female sex has a lower average death rate than the male. If the populations of these cities differ much from the standard and from each other in the proportion of the sexes, that fact would exert some influence upon their death rates. To show whether the populations of these cities do thus differ, Table XXX (see Appendix) has been prepared, showing the per cent. of each sex in the total population at the last available census.

From the last column of Table XXX it appears that in each of the four cities the females outnumber the males. In New York City the difference is insignificant—only four in ten thousand; in the other three cities the difference is much greater—in Berlin 346, in London 596 and in Paris 638 in ten thousand. The effect of this difference between New York and the three great European capitals would be to raise the crude or uncorrected death rate of New York City. To test the fact and measure the amount of this influence, I have taken the average death rates by sex in England and Wales during the decade 1891-1900 and those in the registration area of the United States in 1900 as standards and applied them to the male and female population of each of the four cities. The results appear in Table XXXI.

In such a computation, which shows merely the effect of diversities in sex proportions, the city with the largest proportion of females, Paris, naturally has the lowest death rate and the city with the smallest proportion of females, New York, the highest death rate. But the difference between these extremes, a difference which measures the effect of divergencies in sex proportion upon the death rate, is only two-fifths of one per cent. of the death rate in Paris.

The death rate is modified by divergencies in age distribution far more than it is by divergencies in sex distribution. This is due to two coöperating causes: (1) cities differ from one another in the proportions of their population at various ages far more than they differ in the proportions of the two sexes; (2) age periods differ from one another in death rates far more than the sexes differ.

To ascertain the differences in the age proportions of the population of the four cities, Table XXXII has been prepared. The italicized and bracketed figures for Paris are those in which only the total for the period is known. This total has been distributed to its divisions by assuming that the proportion in Paris agreed with the average proportions in the other three cities. The same method of estimating has been used in a few other cases in later tables.

Both table and diagram show very wide differences between the cities. In New York children under five years of age make more than one tenth of the population; in Paris they make only one sixteenth. On the other hand, in New York people 45 to

49 years of age make one nineteenth of the population, while in Paris they make one fourteenth. Similar differences appear up and down the scale of age periods. These periods may be grouped into two main classes, the healthy ages and the unhealthy ages, the former including the periods during which the death rate is below the average rate at all ages, the latter including the periods during which the death rate is above that average rate. The healthy ages are approximately those from 5 to 54 years; the unhealthy ages are those below the age of 5 or above the age of 54. The proportion of persons at healthy ages, as thus defined, varied from 81.96 per cent. for New York, down to 78.47 per cent. for London. Among every ten thousand residents of New York there are 249 more than there are in London who belong to the healthy ages. These two differences between New York and the other three cities influence the death rate in opposite ways, the large proportion of males tending to raise the rate and the large proportion of persons at healthy ages tending to lower it.

The next step is to measure the net effect of these differences in age distribution, as the net effect of differences in sex distribution has already been measured. In doing so I have used, as before, two sets of standard death rates; the first those shown by the population of England and Wales during the last decade available, 1891-1900, and the second those shown by the population of the registration area of the United States in 1900. These two sets of death rates are shown in Table XXXIII; those for the registration area of the United States in 1900 computed from MSS. furnished by the Census Bureau; those for England and Wales taken from the *Decennial Supplement* for 1891-1900.

The number of deaths computed by comparison with each standard and the resulting computed death rates corrected for age distribution are shown in Tables XXXIV and XXXV. They show that, if correction is made for age distribution alone, New York City would have a lower death rate than any of the other three cities; Table XXXI has shown that, if correction is made for sex distribution alone, New York City would have a higher death rate than any of the other three cities. The general result of these two comparisons is clearly apparent from the following summary, in which the death rate of New York City has been taken as the base, or 1,000, and the rates in other cities compared with it.

TABLE XXVI

DEATH RATES OF LONDON, PARIS AND BERLIN CORRECTED SEPARATELY FOR SEX AND FOR AGE AND COMPARED WITH THE CORRESPONDING DEATH RATES FOR NEW YORK AS A BASE=1,000

CITY	Corrected for Sex Only by Comparison with		Corrected for Age Only by Comparison with	
	U. S. Registration Area	England and Wales	U. S. Registration Area	England and Wales
New York	1,000	1,000	1,000	1,000
Berlin	998	998	1,017	1,020
Paris	997	996	1,047	1,049
London	997	997	1,116	1,134

The foregoing summary shows that, whichever standard is used, the cities stand in the same order and with somewhat similar differences between them. It shows also that the sex distribution of population in New York would tend to produce a high death rate and the age distribution would tend to produce a low death rate in comparison with the other cities. It suggests that in the case of New York the influence of the favorable age distribution upon the death rate is probably greater than the influence of the unfavorable sex distribution. But it does not afford any way of measuring the net or resultant effect of those two opposing influences. Which is the stronger and how much stronger is it?

To answer this question the population of each of the four cities has been distributed both by sex and by age. The results of this distribution are expressed in Table XXXVI. Then the number in each sex and age class in each city, *e. g.*, the number of female children under 5 years of age in Paris, has been multiplied by the death rate of that class in each of the two areas given in Table XXXVII, the products appearing in Tables XXXVIII and XXXIX. In those tables the products showing the computed deaths have been summed and the total divided by the total population. The quotients show the death rates which would have been found in each city if its death rate at each sex and age period had agreed exactly with that of the corresponding sex and age period in the standard population. This quotient is called the *standard death rate.*

The differences between the standard death rates do not correspond at all to the actual differences in the healthfulness of these four cities, for by hypothesis all such actual differences have been excluded, and the death rate of a given sex and age class is the same in all four cities. They do, however, measure at least approximately the effect of the only differences which remain, the differences in sex and age composition. The general result of such a computation appears in the following summary:

TABLE XXVII

STANDARD DEATH RATES OF NEW YORK, LONDON, PARIS AND BERLIN CORRECTED FOR BOTH SEX AND AGE BY ASSUMING THE DEATH RATES IN THE REGISTRATION AREA OF THE UNITED STATES, 1900, AND THOSE IN ENGLAND AND WALES, 1891-1900, AS STANDARDS

CITY	Standard Death Rate Accepting the Rates in		Ratio of Standard Death Rate to that of New York = 1000	
	U. S. Registration Area 1900	England and Wales 1891–1900	U. S. Registration Area 1900	England and Wales 1891–1900
New York	16.08	15.91	1,000	1,000
Berlin	16.28	16.12	1,012	1,012
Paris	16.80	16.58	1,045	1,042
London	17.92	17.96	1,114	1,129

The preceding summary shows that New York City has a standard death rate lower than that in either population with which it is compared or that in any one of the other three cities. In other words, the combined or resultant effect of its sex and age composition is to lower rather than raise its death rate. This influence is more marked in New York than in any of the other cities, for the standard death rate of Berlin is 1-2 per cent. higher, that of Paris 4-5 per cent. higher and that of London 11-13 per cent. higher than that of New York.

After this complicated process has yielded the standard death rate, the next step is to find the factor for correction in each city, or, in other words, the ratio by which the crude death rate of the city must be multiplied in order to get the death rate corrected for diversities in sex and age distribution, or, briefly, the corrected death rate. The results are shown below.

TABLE XXVIII

City	Standard Death Rate Based on		Factor for Correction Based on	
	U. S. Registration Area	England and Wales	U. S. Registration Area	England and Wales
New York	16.08	15.91	1.091	1.144
Berlin	16.28	16.12	1.083	1.128
Paris	16.80	16.58	1.045	1.097
London	17.92	17.96	.979	1.013

The factors for correction indicate the ratio by which the crude death rate of the city in question should be changed before it is fair to compare it with the crude death rate of the standard population. Each standard population must yield its own series of factors for correction and it is far from surprising that they differ widely.

The final step in the process is to multiply the recorded or crude rates by these factors for correction and thus obtain two sets of corrected death rates, one derived from each standard population. The crude rates are given in Table XL; the corrected rates in Tables XLI and XLII. In the seven years 1900-1906, New York City had a higher crude death rate than any of the other three cities, but in the five years 1907-1911, the crude death rate of Paris was higher than that of New York. Each of these three tables contains 32 death rates to be compared with the death rate in New York. Of the 32 crude rates, 27 are below those of New York for the same year; of the 32 corrected rates, 29 are below those of New York for the same year. But the main effect of correction is to widen the differences between the cities. This appears from the following summary in which 1 and 2 refer to the United States Registration area and England and Wales, respectively:

TABLE XXIX

DIFFERENCE BETWEEN THE DEATH RATE OF NEW YORK AND THAT OF LOWEST CITY IN YEAR SPECIFIED

Year	Difference in		
	Crude Rate	Corrected Rate	
		1	2
1900	2.0	4.3	4.8
1901	2.8	5.0	5.5
1902	2.4	2.8	3.0
1903	2.8	4.7	5.2
1904	4.0	6.1	6.7
1905	3.3	5.3	5.8
1906	3.2	5.2	5.6
1907	3.7	5.7	6.1
1908	2.5	4.3	4.6
1909	2.0	3.8	4.1
Average	2.9	4.7	5.1

So long as the death rate of New York remains nearly or quite as high as that of any of the other cities, and the sex and age composition of the several populations remains substantially as at present, the effect of correction will be to increase the differences between New York and the other cities. But if New York's death rate should become nearly or quite as low as that of any of the other cities, then the effect of correction would be to decrease the differences between the extremes.

Yours respectfully,
WALTER F. WILLCOX.

November 10, 1913.

APPENDIX

TABLE XXX

SEX PROPORTION OF THE TOTAL POPULATION IN NEW YORK CITY, LONDON, PARIS AND BERLIN

CITY	Date of Census	Total Population	Males	Females	Per Cent.		Excess of Females
					Male	Female	
New York[1]	1910	4,766,883	2,382,482	2,384,401	49.98	50.02	0.04
London[2]	1911	4,521,685	2,126,341	2,395,344	47.02	52.98	5.96
Paris[3]	1906	2,719,924	1,273,144	1,446,780	46.81	53.19	6.38
Berlin[4]	1905	2,040,148	984,804	1,055,344	48.27	51.73	3.46

[1] The figures for New York in this and later tables are derived from proof sheets kindly furnished me by the Census Bureau.

[2] The figures for London in this and later tables are derived from Census of England and Wales, 1911, Vol. VII, kindly sent me from the General Register Office. They apply to "Registration London," excluding the "Outer Ring," and include thus not much more than three-fifths of the population of "Greater London."

[3] The figures for Paris in this and later tables are derived from the Census of France, 1906, Vol. 1, Part 2, pp. 160–165.

[4] The figures for Berlin in this and later tables are derived from *Stat. Jahrbuch d. Stadt Berlin*, Vol. 31, p. 1.

TABLE XXXI

COMPUTED DEATH RATES OF NEW YORK CITY, LONDON, PARIS AND BERLIN CORRECTED FOR DIFFERENCES IN SEX PROPORTION

CITY	Sex	Population of Known Age	Death Rate of U. S. Registration Area, 1900	Computed Deaths by Sex	Sum of Deaths	Computed Death Rate	Death Rate of England and Wales, 1891–1900	Computed Deaths by Sex	Sum of Deaths	Computed Death Rate
New York	Male	2,382,482	18.57	44,240	83,650	17.55	19.32	46,030	86,900	18.23
	Female	2,384,401	16.53	39,410			17.14	40,870		
London	Male	2,126,341	18.57	39,482	79,080	17.49	19.32	41,081	82,137	18.17
	Female	2,395,344	16.53	39,598			17.14	41,056		
Paris	Male	1,273,144	18.57	23,642	47,560	17.49	19.32	24,595	49,395	18.16
	Female	1,446,780	16.53	23,918			17.14	24,800		
Berlin	Male	984,804	18.57	18,288	35,732	17.51	19.32	19,025	37,115	18.19
	Female	1,055,344	16.53	17,444			17.14	18,090		

TABLE XXXII

Age Proportion of the Population of Known Age of New York, London, Paris and Berlin

Age Period	New York City, 1910	London, 1911	Paris, 1906	Berlin, 1905
All ages	10,000	10,000	10,000	10,000
Under 5	1,065	1,034	632	876
5— 9	920	960	600	816
10—14	887	889	617	773
15—19	961	897	791	930
20—24	1,118	948	997	1,154
25—29	1,049	930	1,151	1,115
30—34	888	830	1,037	905
35—39	803	746	917	791
40—44	651	641	810	665
45—49	517	551	701	548
50—54	402	455	*548* [*]	442
55—59	256	352	*396*	351
60—64	199	279	310	258
65—69	131	212	228	177
70—74	82	144	*143* [*]	105
75—79	42	79	*78*	58
80—84	20	36	*30* [*]	27
85—89	7	13	*11*	8
90+	2	4	*3*	1

[*] Estimated from the total figures 50–59, 70–79 or 80 and over, by applying the average proportions in the other three cities.

TABLE XXXIII

Death Rates by Age Periods in the Registration Area of the United States, 1900, and in England and Wales, 1891-1900, Taken as Standard Populations

Age Period	Death Rates of: United States Registration Area, 1900	Death Rates of: England and Wales, 1891–1900	Age Period	Death Rates of: United States Registration Area, 1900	Death Rates of: England and Wales, 1891–1900
Under 5	51.81	57.74	55—59	25.43	31.47
5— 9	5.08	4.34	60—64	34.64	
10—14	3.25	2.51	65—69	50.75	65.04
15—19	5.18	3.73	70—74	73.98	
20—24	7.36	4.74	75—79	109.24	152.17
25—29	8.37	6.40	80—84	167.45	
30—34	9.56		85—89	241.39	
35—39	10.52	10.51	90—94	334.58	
40—44	12.03		95+	401.75	
45—49	14.69	16.76			
50—54	18.78				

TABLE XXXIV

COMPUTED DEATH RATE OF NEW YORK CITY, LONDON, PARIS AND BERLIN CORRECTED FOR DIFFERENCES IN AGE PROPORTION BY USING THE DEATH RATES IN THE REGISTRATION AREA OF THE UNITED STATES IN 1900 AS A STANDARD

AGE PERIOD	Computed Deaths at Specified Age Period in			
	New York	London	Paris	Berlin
Under 5	26,272	24,217	8,875	9,252
5— 9	2,226	2,203	828	845
10—14	1,373	1,306	545	513
15—19	2,370	2,101	1,111	982
20—24	3,915	3,156	1,990	1,731
25—29	4,178	3,521	2,613	1,902
30—34	4,039	3,588	2,687	1,766
35—39	4,021	3,547	2,619	1,697
40—44	3,728	3,487	2,640	1,630
45—49	3,615	3,658	2,791	1,644
50—54	3,589	3,866	2,789	1,692
55—59	3,108	4,046	2,734	1,818
60—64	3,270	4,370	2,917	1,820
65—69	3,169	4,830	3,139	1,814
70—74	2,906	4,788	2,880	1,587
75—79	2,196	3,902	2,300	1,302
80—84	1,540	2,786	1,401	921
85—89	781	1,298	707	401
90—94	286	493	227	73
95+	80	93	49	8
Total deaths	76,662	81,256	45,842	33,398
Computed death rate	16.10	17.97	16.86	16.38

TABLE XXXV

COMPUTED DEATH RATE OF NEW YORK CITY, LONDON, PARIS AND BERLIN CORRECTED FOR DIFFERENCES IN AGE PROPORTION BY USING THE DEATH RATES OF ENGLAND AND WALES IN 1891-1900 AS A STANDARD.

AGE PERIOD	Computed Deaths at Specified Age Period in			
	New York	London	Paris	Berlin
Under 5	29,279	26,988	9,891	10,310
5— 9	1,902	1,882	707	722
10—14	1,060	1,009	421	396
15—19	1,707	1,513	800	707
20—24	2,521	2,033	1,282	1,115
25—34	5,898	5,094	3,797	2,636
35—44	7,274	6,591	4,923	3,119
45—54	7,327	7,624	5,672	3,386
55—64	6,816	8,976	6,033	3,903
65—74	6,616	10,461	6,555	3,744
75+	5,122	9,147	5,045	2,939
Total deaths	75,522	81,318	45,126	32,977
Computed death rate	15.86	17.98	16.64	16.17

TABLE XXXVI

Sex and Age Distribution of Population of New York, London, Paris and Berlin to Each 10,000 of Known Age

Age Period	New York, 1910		London, 1911		Paris, 1906		Berlin, 1905	
	Male	Female	Male	Female	Male	Female	Male	Female
All ages	4,995	5,005	4,702	5,298	4,686	5,314	4,827	5,173
Under 5	537	528	519	515	315	317	440	436
5— 9	460	460	478	482	296	304	407	409
10—14	442	445	440	449	304	313	380	393
15—19	454	507	427	470	380	411	445	485
20—24	528	590	422	526	428	569	594	560
25—29	533	516	419	511	551	600	560	555
30—34	462	426	385	445	505	532	451	454
35—39	413	390	349	397	436	481	388	403
40—44	339	312	301	340	391	419	322	343
45—49	268	249	259	292	334	367	249	299
50—54	207	195	214	241	254 *	293 *	198	244
55—59	128	128	164	188	179	218	153	198
60—64	95	104	128	151	132	178	107	151
65—69	62	69	93	119	90	138	68	109
70—74	37	45	58	86	52 *	91 *	37	68
75—79	18	24	29	50	26	52	18	40
80—84	8	12	12	24	9 *	21 *	8	19
85—89	3	4	4	9	3	8	2	6
90+	1	1	1	3	1	2	0	1

* Estimated from the total figures 50–59, 70–79 or 80 and over, by applying the average proportions in the other three cities.

TABLE XXXVII

Death Rates by Age and Sex in the Registration Area of the United States, 1900, and in England and Wales, 1891-1900, Taken as Standard Populations

Age Period	Death Rates of			
	United States Registration Area, 1900		England and Wales, 1891–1900	
	Male	Female	Male	Female
Under 5	56.22	47.34	62.71	52.80
5— 9	5.18	4.97	4.31	4.37
10—14	3.29	3.21	2.45	2.57
15—19	5.27	5.10	3.79	3.67
20—24	7.73	7.01	5.06	4.46
25—29	8.59	8.15	6.76	6.08
30—34	9.54	8.71		
35—39	11.24	9.74	11.50	9.59
40—44	12.99	10.98		
45—49	16.16	13.14	18.95	14.74
50—54	20.50	18.01		
55—59	27.52	23.35	34.95	28.44
60—64	37.49	31.92		
65—69	54.76	46.98	70.39	60.72
70—74	78.06	70.14		
75—79	115.70	103.40	160.09	146.46
80—84	175.40	160.90		
85—89	252.90	232.80		
90—94	350.60	325.20		
95+	411.80	402.40		

TABLE XXXVIII

COMPUTED DEATH RATE OF NEW YORK CITY, LONDON, PARIS AND BERLIN CORRECTED FOR DIFFERENCES IN SEX AND AGE PROPORTION BY USING THE DEATH RATES IN THE REGISTRATION AREA OF THE UNITED STATES IN 1900 AS A STANDARD

AGE PERIOD	Computed Deaths							
	Male				Female			
	New York	London	Paris	Berlin	New York	London	Paris	Berlin
Under 5...........	14,380	13,187	4,796	5,042	11,900	11,023	4,070	4,207
5— 9...........	1,134	1,118	416	430	1,090	1,052	411	415
10—14...........	692	655	272	255	679	652	273	257
15—19...........	1,139	1,018	543	478	1,232	1,083	570	504
20—24...........	1,942	1,477	897	935	1,969	1,669	1,083	801
25—29...........	2,178	1,629	1,283	979	2,002	1,883	1,327	922
30—34...........	2,098	1,660	1,306	878	1,765	1,753	1,256	807
35—39...........	2,209	1,775	1,331	889	1,809	1,746	1,272	801
40—44...........	2,096	1,767	1,376	852	1,631	1,690	1,247	768
45—49...........	2,061	1,891	1,462	822	1,558	1,734	1,307	802
50—54...........	2,020	1,988	1,411	827	1,667	1,961	1,432	896
55—59...........	1,681	2,036	1,338	859	1,427	1,987	1,378	941
60—64...........	1,687	2,162	1,343	817	1,576	2,186	1,544	982
65—69...........	1,619	2,313	1,341	756	1,544	2,531	1,756	1,048
70—74...........	1,388	2,031	1,174	587	1,508	2,715	1,730	977
75—79...........	986	1,530	817	431	1,198	2,325	1,454	847
80—84...........	649	989	454	275	884	1,770	928	633
85—89...........	316	458	211	114	463	988	489	283
90—94...........	105	130	61	20	181	358	165	52
95+.............	24	25	12	2	56	69	37	6
Total, known age...	40,404	39,839	21,844	16,248	36,139	41,175	23,729	16,949
Both sexes.........	76,543	81,014	45,573	33,197				
Standard death rate.	16.08	17.92	16.80	16.28				

TABLE XXXIX

COMPUTED DEATH RATE OF NEW YORK CITY, LONDON, PARIS AND BERLIN CORRECTED FOR DIFFERENCES IN SEX AND AGE PROPORTION BY USING THE DEATH RATES IN ENGLAND AND WALES, 1891-1900, AS A STANDARD

AGE PERIOD	Computed Deaths							
	Male				Female			
	New York	London	Paris	Berlin	New York	London	Paris	Berlin
Under 5...........	16,037	14,708	5,351	5,625	13,272	12,295	4,540	4,693
5— 9...........	944	931	347	358	958	951	361	365
10—14...........	516	488	202	190	544	522	218	206
15—19...........	819	733	390	344	886	779	409	363
20—24...........	1,271	966	587	612	1,252	1,061	689	509
25—34...........	3,200	2,458	1,935	1,393	2,725	2,629	1,867	1,251
35—44...........	4,116	3,380	2,580	1,664	3,205	3,194	2,341	1,459
45—54...........	4,282	4,055	3,019	1,728	3,112	3,551	2,638	1,633
55—64...........	3,707	4,602	2,954	1,852	3,144	4,367	3,054	2,020
65—74...........	3,333	4,804	2,723	1,501	3,302	5,624	3,767	2,200
75+.............	2,214	3,379	1,711	928	2,894	5,712	3,299	1,980
Total, known age...	40,439	40,504	21,799	16,195	35,294	40,685	23,183	16,679
Both sexes.........	75,733	81,189	49,982	32,874				
Standard death rate.	15.91	17.96	16.58	16.12				

TABLE XL

Crude Death Rates of New York, Berlin, Paris and London, 1900-1909

Date	Crude Death Rates of			
	New York[1]	Berlin[2]	Paris[3]	London[4]
1900	20.6	19.0	19.6	18.6
1901	19.9	18.1	18.7	17.1
1902	18.6	16.2	18.3	17.2
1903	18.0	16.6	17.4	15.2
1904	20.1	17.0	17.7	16.1
1905	18.4	17.1	17.6	15.1
1906	18.3	15.8	17.6	15.1
1907	18.3	15.4	18.4	14.6
1908	16.3	15.4	17.4	13.8
1909	16.0	15.1	17.2	14.0
1910	16.0	....	16.2	....
1911	15.2	....	17.2	....

[1] Figures for New York are derived from Bureau of the Census, *Mortality Statistics*, 1909, p. 72, *Bulletin* 109, p. 46 and *Bulletin* 112, p. 43.

[2] Figures for Berlin are derived from *Stat. Jahrbuch der Stadt Berlin*, XXXII, p. 111.

[3] Figures for Paris are derived from *Annuaire Stat. de la Ville de Paris*, XXXI, p. 200.

[4] Figures for London are derived from *Report of Medical Officer of Health of London County*, 1908, p. 8.

TABLE XLI

Corrected Death Rates of New York, Berlin, Paris and London, Using the United States Registration Area, 1900, as a Standard

Date	Corrected Death Rates of			
	New York	Berlin	Paris	London
1900	22.5	20.6	20.5	18.2
1901	21.7	19.6	19.5	16.7
1902	20.3	17.5	19.1	16.8
1903	19.6	18.0	18.2	14.9
1904	21.9	18.4	18.5	15.8
1905	20.1	18.5	18.4	14.8
1906	20.0	17.1	18.4	14.8
1907	20.0	16.7	19.2	14.3
1908	17.8	16.7	18.2	13.5
1909	17.5	16.4	18.0	13.7
1910	17.5	....	16.9	....
1911	16.6	....	18.0	....

TABLE XLII

Corrected Death Rates of New York, Berlin, Paris and London, Using England and Wales, 1891-1900, as a Standard

Date	Corrected Death Rates of			
	New York	Berlin	Paris	London
1900	23.6	21.4	21.5	18.8
1901	22.8	20.4	20.5	17.3
1902	21.3	18.3	20.1	17.4
1903	20.6	18.7	19.1	15.4
1904	23.0	19.2	19.4	16.3
1905	21.1	19.3	19.3	15.3
1906	20.9	17.8	19.3	15.3
1907	20.9	17.4	20.2	14.8
1908	18.6	17.4	19.1	14.0
1909	18.3	17.0	18.9	14.2
1910	18.3	....	17.8	....
1911	17.4	....	18.9	....

SECTION II

CHEMICAL OXIDATION AS A PROCESS OF SEWAGE TREATMENT AND A REPORT BY SAMUEL RIDEAL ON OXIDATION PROCESSES APPLICABLE TO NEW YORK CONDITIONS

The object of oxidizing New York's sewage, partly or completely, by chemicals would be to remove the excessive demand which the sewage makes on the dissolved oxygen in the harbor water and so permit the sewage to be discharged into the inner harbor with little or no other treatment.

Aeration and Chemical Oxidation Compared

Forced aeration has been suggested for this purpose by various investigators, as it has previously been proposed for other situations and as it has subsequently been recommended in connection with various biological processes, but aeration is not a process in itself. Its function is not to oxidize sewage, but to supply the oxygen with which the ordinary purifying forces of nature can carry the oxidizing processes forward. Its benefits are slow for they depend not only upon the rate at which sewage will absorb oxygen, but upon the rate at which the natural purifying agencies will appropriate it.

Aeration is especially useful where the oxygen supply is deficient, for then the rate at which the water will absorb it is relatively high. Water and sewage absorb oxygen at the same rate and to the same extent and, as has been shown elsewhere, when there is a considerable amount of dissolved oxygen present, it is difficult to add more by aeration or by any other means. Where large quantities of oxygen have to be supplied by aeration, it is necessary to continue the process over a long period of time or to repeat it at frequent intervals. Either of these alternatives is likely to prove expensive for the reason that they make it necessary to provide means for keeping the sewage on hand for a considerable period.

Chemical oxidation seeks to eliminate the slowness and inconvenience of the aeration process and, by aiming directly at the desired reaeration, to affect a material gain. Unlike aeration, chemical oxidation is a radical form of treatment which involves abrupt interruption in the natural course of self purification which sewage ordinarily undergoes from the moment it is produced until its harmful properties are rendered inert, and in which living organisms play an important part. Chemical oxidation, by whatever method it is carried on, means a sudden arresting of the natural purifying agencies, a rapid and intense chemical reaeration between the oxidizing agent and the oxidizable ingredients of the sewage and the final discharge of the effluent in a state which is not inimical to the fauna and flora of the natural body of water into which it is emptied. Incidentally, the oxidation produces disinfection and the disinfecting properties of the oxidizing matter in some cases prove to be advantageous. Under other and more usual circumstances, it may prove embarrassing, as, for example, where a large amount of sewage effluent possessing antiseptic properties is discharged into water which is inhabited by fishes.

The use of chemicals to purify sewage is by no means a new idea, although there are apparently no existing large sewage works where chemical oxidation is practiced to serve as an example of the size and arrangement of apparatus needed and the cost, efficiency and reliability of the process. Nevertheless, considerable help in forming an opinion on the leading difficulties to be overcome can be obtained from the experience gained with certain standard processes of water and sewage treatment, notably the application of basic sulphate of alumina, lime and iron, copper sulphate and hypochlorite.

Intended Scope of Dr. Rideal's Report

Experiments on the purification of New York's sewage through the electrolytic decomposition of sea water by the application of bleach and by chlorine led the Commission, in 1912, to seek the opinion of an eminent expert on chemical questions relating to the purification of sewage and disinfection, and Dr. Samuel Rideal of London was requested to make a report on the possibilities of direct chemical oxidation.

Dr. Rideal, a Doctor of Science, Fellow of the University College, Fellow of the Institute of Chemistry and of the Sanitary Institute of Great Britain and Vice-President of the Society of Chemical Analysts of Great Britain, is the author of "Sewage and the Bacterial Purification of Sewage," "Water and its Purification," and "Disinfection and Disinfectants," all of which have passed through several editions.

In preparation for his report, Dr. Rideal made a personal inspection of the conditions of sewage disposal in New York harbor and visited the Commission's office to become familiar through conferences and study with the results of the Commission's work. His report is a discussion of the questions assigned to him from a chemical and theoretical standpoint and makes no claim either to finality or practicability, which he rightly says would not be warranted in "so short a report nor without a prolonged study of the main details chiefly of an engineering character."

In a letter dated October 3, 1912, the Commission requested Dr. Rideal to report on "other ways of oxidizing sewage than by biological means, that is, through the use of chemicals. Absence of odor, restricted areas of land and freedom in the effluent from substances poisonous to fishes should be features of such procedures. It should be remembered also that the process must be applicable to large volumes of sewage—not less than 25,000,000 or 30,000,000 gallons per 24 hours, for example. The cost of the treatment, including the purchase of materials should not be excessive, nor should the process involve expense for pumping. Inasmuch as processes for the chemical oxidation of sewage are not in general use, it will be desirable to give such assurance as is possible that any process suggested can actually be carried out."

In addition to his opinion on chemical oxidation, Dr. Rideal was asked if, in his view, the Commission was right in placing importance on the presence of sludge on the harbor bottom as an element making for the exhaustion of oxygen from the water, whether he considered it possible to purify the sewage sufficiently near its points of origin to permit the effluent to be discharged into the inner harbor and to give his impression of the condition of the harbor as he saw it on his trip from the Battery to Hell Gate on October 2, 1912.

Synopsis of the Report

It is Dr. Rideal's opinion that all the sewage produced now and in the next generation in the metropolitan district of New York and New Jersey can be sufficiently purified on properly selected sites near where it is produced to permit of its discharge locally into the waters of the inner harbor without violating any of the provisions of the Commission's standard of cleanness. The purification works, he thinks, should be able to remove the unsightly and offensive floating suspended matters of the sewage and insure that the effluent becomes invisible and inodorous when mixed with the harbor waters. So far as oxidation is concerned, Dr. Rideal thinks that sufficient oxidizing treatment should, and can, be given to the sewage to keep the effluent from absorbing more than one-half of the oxygen in the harbor water.

The reagents which are considered available for the oxidation of the sewage are few in number. They include manganates and permanganates and oxidized compounds of chlorine. The first two would be prohibitively costly. Even the cost of hypochlorite, the cheapest oxidizing agent, would be too expensive for use with crude sewage, according to Dr. Rideal's report. It would be necessary to use it as a finisher to the mechanical or bacterial process which would remove much of the floating suspended matters. Sedimentation basins having from 4 to 20 hours' flow are suggested to accomplish the removal of the solids, the basins to operate on the principle of septic tanks or sludge-digesting tanks.

In addition to their main function of retaining and digesting the solids so as to reduce the cost of the chemicals, the basins would prevent sludge from forming on the harbor bottom. In Dr. Rideal's opinion, the advantage to be gained in this respect would be of small value, for he does not think that the sludge deposits in New York harbor are as responsible as the liquid part of the sewage in exhausting the dissolved oxygen from the water.

If it was not possible to secure space for septic or sludge-digesting tanks on land, Dr. Rideal thinks the tanks could be erected in the water along Manhattan Island and elsewhere with the necessary chemical equipments by their side. He suggests that the basins be covered to prevent nuisance. The sludge having attained its main decomposition without oxygen could, in Dr. Rideal's opinion, be discharged into the harbor with no fear of absorbing much oxygen afterward. The effluent should be treated at the outlet by a small quantity of the oxidizer. By the use of such tanks as he proposes, Dr. Rideal thinks that hardly any pumping would be required.

The report contains calculations on the amount of chlorine necessary and, in these, due account is taken of the oxygen required by the sewage, the quantity of oxygen which is brought by tidal action into the harbor from the ocean, that which is contributed by the land water from the rivers and that which is absorbed from the atmosphere. The object of the chemical process would be to supply only enough oxidation to supplement the natural process which proceeds in the harbor.

To completely oxidize the 1,500,000,000 gallons per day of sewage included in the estimates, Dr. Rideal finds that 1,280 tons of available chlorine would be required per day. Basing his opinion on experiments made with Philadelphia sewage, the report indicates that New York harbor sewage could be disinfected with a good quality of chloride of lime in the proportion of 27.9 tons for screened sewage and 19.5 tons for screened and settled sewage. In another way it is calculated that six parts per million is the proper dose which is likely to prove effectual.

The chlorine could be added, in Dr. Rideal's opinion, in the form of chlorine gas, bleaching powder or as sodium hypochlorite produced from an electrolyzed solution of sodium chloride. The supply of sodium chloride could be obtained from the harbor water or from a solution of rock salt. Sea water might not be strong enough for practical purposes, its weakness possibly requiring works of too large size. Electric bleach works usually operate with 5 to 15 per cent. sodium chloride solutions.

A considerable part of Dr. Rideal's report is devoted to the question of forced aeration as a method of sewage disposal and the results of various calculations are given to show that it would be impracticable to oxidize New York sewage by this means. At the conclusion, the report recommends that chlorine treatment be given serious consideration along the two following lines: 1, Preliminary screening and sedimentation to produce a non-fermenting sludge which can be discharged into the harbor waters separately without robbing them of any dissolved oxygen, and, 2, a chlorine treatment of the clarified effluent to such an extent as will insure the proposed minimum standard of 3 c.c. of dissolved oxygen per litre being maintained throughout the whole of the harbor waters.

The Commission's Opinion

The Commission has given careful consideration to Dr. Rideal's recommendation and as a result does not regard his proposition as affording a practical solution of New York's sewage problem.

Experiments have shown that the amount of chlorine which it would be necessary to apply to settled sewage in order to produce a material reduction in the dissolved oxygen required would be so great, its sterilizing effects so powerful and its odor so penetrating as to make it probable that the entire harbor would become sterilized and smell disagreeably of the disinfectant.

Theoretically a powerful oxidizing agent, chlorine appears to be capable of producing an appreciable oxidizing effect upon sewage only in concentrations which it is impracticable to employ. In moderate concentration it is a poisonous gas easily soluble in water, from which it can be completely driven only with difficulty.

Hitherto chlorine and hypochlorite have been used in water and sewage treatment only as disinfectants, minute doses being usually sufficient to accomplish the desired end. In the arts, chlorine compounds are used extensively for bleaching purposes. There are no works for the chemical oxidation of sewage now operating upon this principle and it appears impossible to give reasonable assurance that the process suggested can actually be carried out. Used as a disinfectant, the Commission is of opinion that chlorine perhaps prepared from electrolyzed sea water may be found to be of considerable service in dealing with certain parts of New York's sewage.

The cost of oxidizing the sewage by means of chlorine would be excessive, especially in view of the ample provision which would have to be made for the preliminary septic tanks or basins capable of producing a non-fermenting sludge. It is not clear why the fermentation of sludge appears to the author of the report to be a necessary step in the process. If thorough sedimentation could be provided for all the sewage entering the harbor, it would seem from the Commission's researches to be permissible to dispense with the oxidizing process.

The idea of discharging fermented sludge into the harbor is apparently contrary to the federal laws which have been enacted for the protection of the navigable channels against shoaling.

REPORT OF SAMUEL RIDEAL

DR. GEORGE SOPER,
PRESIDENT, METROPOLITAN SEWAGE COMMISSION OF NEW YORK.

DEAR DR. SOPER: Since my inspection with you of the New York Harbor, and especially the East river, on October 2d, I have read your two reports with much interest and will now try and answer the questions which you have put to me in your letter of October 3d.

Before doing so, however, I should like to congratulate the Commission upon the very valuable information which these reports contain, and the clearness with which the facts have been marshalled; so far as I have at present been able to study the problem, I feel that the proposed standards* are both desirable and feasible, and it is to be hoped that the treatment of the sewage of your future population will be designed in such a way as will ensure that the standards will not be infringed.

You ask my opinion on the condition of the Harbor water as I saw it on my trip of inspection on October 2d, and I must say that I was surprised that a city claiming to be one of the first in the world should allow such a disgraceful condition of affairs to exist even for a moment. One cannot blame the past for creating a city population on an island surrounded by land-locked waters, nor complain of its rapid development to the surrounding shores, but surely for many years past such an unfortunate condition of the Harbor waters and banks of your great city should have prompted the authorities to have earnestly tackled this great blot upon your civilization earlier in the development of your city. I understand that whilst the work of your Commission has been in progress during the past few years, your neighbors in New Jersey, to whom the purity of the Harbor waters is of equal importance, have not joined hands with the City of New York and associated themselves with the desire to stop the discharge of unpurified sewage and polluting waters into the Harbor. In my opinion it behooves the two States to work hand in hand at once in order to satisfactorily solve the problem, and that further delay must inevitably lead to serious sanitary troubles which will militate against the life and well-being and future prosperity, of not only the riparian population, but of the whole of your great metropolis.†

The main question which you have asked me to consider can hardly be dealt with in a short report nor without a prolonged study of the main details chiefly of an engineering character. Assuming a collaboration of the whole of the authorities now polluting the Harbor waters, I am of the opinion that our present knowledge of sewage purification makes it possible to sufficiently purify the sewage in the territory on properly selected local sites so that the effluent may be harmlessly discharged into the waters. In making this positive statement and thus giving an affirmative answer to your question so definitely, I am guided by the evidence which you have collected, which shows that at the present time the waters of the inner Harbor, as a whole, have not under present conditions fallen below your suggested standards, and that it will be possible in the future to banish bathing and oyster culture (as suggested in your 5th standard) from any part of the Harbor north of the Narrows, or in the Arthur Kill, and to deal specially with Jamaica Bay and elsewhere where these two are practised.

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*The Degree of Cleanness Which is Necessary and Sufficient for the Water. See the Commission's Report of August, 1912, Part II, Chapter I, Page 70.

†The Metropolitan Sewerage Commission endeavored to secure the co-operation of New Jersey in its work, but without result. See Report of April, 1910, Part I, Chapter I, Page 43.

We have then to recollect that the problem kept foremost in a harbor is not to purify the sewage, but a far simpler one, *i. e.,* the removal of unsightly and offensive floating suspended matters, and to ensure that the effluent is invisible and inodorous when mixed with the Harbor water. This being the object in view, I believe that the removal of the floating suspended matter can be effectively carried out locally on restricted areas of land or in restricted areas of water at fixed points, dealing with 25 to 30 million gallons of sewage per 24 hours, and therefore by judicious selection of sites these can be multiplied to deal with the prospected future population, and that, consequently, the heavy costs involved in any scheme of discharging the whole of the sewage to sea at the ocean entrance to the Harbor or disposal on farm land on sewage farms on Long Island, or bacterial treatment on Barren Island, would be negatived.

When you ask me to discuss the methods of oxidizing sewage you mean "how can the waters of New York Harbor be kept half saturated with oxygen as at present."

It would seem at first sight that additional oxygen or air could be directly applied to the Harbor waters to comply with this requirement, and I understand that a method of forced aeration to accomplish this object has been seriously discussed. But I point out further that the rate of absorption of oxygen from air is slow, and that even by agitation the maximum amount of oxygen capable of being absorbed by sewage is approximately the same as that which can be absorbed by water, and we have now the fact, as well shown in your report, that the present flow of sewage is absorbing gradually at the surface the oxygen of the air over the Harbor waters and, in addition, is consuming the dissolved oxygen from these waters to the extent of nearly half.

In reference to your first question, as to other ways of oxidizing the sewage than by biological methods, *i. e.,* by the use of chemicals, the following are the only ones that have practically been found available:

1. *Manganates or Permanganates.* The report of the British Commission of 1882 on the effects of the discharge of the sewage of London into the Thames found that it was possible to thoroughly deodorize (and presumably efficiently sterilize) sewage by permanganate and sulphuric acid (giving ozonized oxygen) either before or after the removal of the suspended matter by precipitation (Vol. XI, p. 142). Sodium manganate, as a cheaper salt, was used for the London sewage from 1884 to 1894 by introducing it into sewers at different points; being strongly alkaline, it disengaged ammonia, which was neutralized by acid treatment at the outfall. The process was expensive, and was generally abandoned in favor of bacterial methods, or lime-iron-alumina precipitations.

There is no doubt that the manganese oxides in the sludge act as carriers of oxygen and promote its oxidation, and Adeney in 1894 founded a process of purification on this fact. It was hoped that the manganese could be economically recovered from the sludge, but this has not yet been done.

2. *Oxidized Compounds of Chlorine* are much more economical. My experience at Guilford is well known, in which I found a great advantage in treating the raw sewage direct with an electrolyzed salt solution, called "oxychloride," containing sodium hypochlorite, instead of using ordinary precipitants of the lime, iron and alumina class. The benefits noticed were (1) disappearance of nuisance, (2) reduction of volume of sewage, (3) stability of sludge and effluent.

In other places "chloros" (a chemically prepared sodium hypochlorite), and bleaching powder (calcium compound), have been used with similar success.

The proportion of these chlorine oxidizers can be easily controlled so that the effluent should be sufficiently sterilized and should be harmless, securing in the terms of your letter:

(a) "absence of odor,"
(b) "restricted areas of land,"
(c) "freedom from substances poisonous to fish."

At the same time the matter is a question of expense.

The hypochlorite treatment involves no "heavy expense for pumping," but the cost of the chemicals if applied to such large volumes of raw sewage would be exceedingly great.

From this arises the necessity of applying mechanical and bacterial processes in the first stage, and reserving the oxidizing agent as a finisher. To quote an example from my own practice, a raw sewage required 50 parts per million of available (active) chlorine for sterilization of pathogenic organisms; after passage through a septic tank about half (24) sufficed; and when passed afterwards through porous gravel, 10 to 5 parts did the same work, proving that it is better to apply a preliminary treatment.

I cannot do better than quote from my book on "Sewage and Its Purification," third edition, p. 188:

> The simple treatment of raw sewage by means of a septic tank and then addition of the solution would be sufficient for a large number of cases where the organic purity was of less importance than the removal of pathogenic organisms, as in localities close to shellfish gathering-grounds or watercress beds. For both of these, and particularly for vegetables, complete organic purification might be a disadvantage, as depriving them of food. In places where open septic tanks had been objected to on account of suggested nuisance, closed tanks could be adopted of a rather smaller size than usual, the solution being added in a covered carrier with baffle plates as the effluent passed out, with a certainty of removing all objectionable odors. If existing tanks are divided by a party wall into two unequal chambers; in the first of say twenty hours' dry weather capacity, the anærobic preparation could go on as at present; while in the second, of say four hours' capacity, the chlorine solution would be added in sufficient quantity to cause the remaining suspended solids to subside in a more or less sterilized condition, and the effluent to be free from smell and objectionable organisms. The cost and space required for primary, secondary and tertiary beds would in this way be saved. I believe that the method, in the case of seaside towns and those discharging into estuaries, would greatly contribute to local healthy conditions, and would ensure the absence of unsightly sewage matter on the shores.

In comparing quantities the sewage in the United States being generally more dilute than that in Europe will require as a rule a smaller amount of oxidant. At the same time *there will be a greater necessity for sterilization, since there will be a larger volume of water fouled.* The map* shows an enormous bacterial increase from the upper parts of East river and the Hudson down to the city. The greater number of these organisms act as scavengers, but a smaller proportion are pathogenic, derived from the inhabitants or animals. It is fortunate that species, like Bacillus typhosus, are more easily killed by chemical treatment than harmless other kinds, like B. subtilis, which are actually useful in breaking up cellulose and organic debris and do their work naturally in sewers and in a septic tank.

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* See the Commission's Report of August, 1912, Part III, Chapter II, Pages 264-5.

With reference to your second question as to whether the presence of sludge on the harbor bottom accounts for the exhaustion of oxygen from the water.

Sludge absorbs oxygen in variable proportions according to its composition, but its action, as a sediment, on a liquid above, particularly when the latter is in motion as in river channels, is very slow. Therefore I agree with your Commission as to the importance of the sludge, but consider that the aqueous liquid of the sewage must be more responsible for the exhaustion of oxygen.

In regard to your remark that "the processes must be applicable to not less than 25 to 30 million gallons for each of many unit plants," I see no reason why units of this character could not be adopted as it would be an advantage to have a separate treatment at each.

If not possible to secure space for the septic or sludge digesting tanks on land, they could be erected in the water along Manhattan Island and in other places similar in form to a large swimming bath, with a sterilizing equipment by the side. A covered tank would prevent any nuisance, and the decomposition, being principally anærobic, as we have found in septic tanks, is not attended by absorption of oxygen, and the sludge, having attained its main decomposition without oxygen, could be discharged with no fear of absorbing much oxygen afterwards.

The effluent could then be treated at the outfall piers with a small quantity of oxidizer and in this way hardly any pumping would be required if the sites were selected with this object in view.

ESTIMATION OF THE AMOUNT OF CHLORINE REQUIRED

Referring to p. 20 of the Metropolitan Sewerage Commission's Report of August, 1912, and calculating the cubic feet into gallons (1 cub. ft. = 7.5 U. S. Gallons), it will be seen that the quantity of water which ebbs and flows through the Narrows may be taken as 90,000 million gallons per tide. The excess of seaward-moving water over that which returns is estimated at 9,750 million gallons per tide. Of this 8,250 million gallons is accounted for by land water coming down from the Hudson and 750 million gallons "flows toward the sea from the tidal actions in the East river." These last factors account together for 9,000 million gallons, and leave an excess of 750 million gallons per tide which is mainly contributed in about equal quantities by the sewage and local drainage entering the Harbor. This will be 1,500 million gallons per 24 hours.

From the fact that the waters entering from above and from below contain an average of 6 cubic centimeters per liter of dissolved oxygen, whereas the water in the inner harbor must not in the future contain less than 3 cubic centimeters per liter, it follows that a reduction of dissolved oxygen of 3 c.c. per liter is permissible. At the same time atmospheric oxygen is dissolving in the water to replace that which has disappeared, so that the actual is greater than the apparent absorption.

From experiments I have made on the absorption of atmospheric oxygen by waters (*Analyst,* London, August, 1901), I notice that it is very slow unless circulation interferes.

Shallow layers (3 inches deep) of the following:

A. Water vigorously boiled in a flask for two hours;

B. Sewage similarly boiled, with addition of boiled water to maintain the volume;

C. Raw sewage;

were kept in a quiet room and the dissolved oxygen determined at intervals. The results are given in the following table:

TABLE XLIII

Hours	Temp. °C.	A. Boiled Water			B. Boiled Sewage			C. Raw Sewage		
		C.C. per Liter Dissolved Oxygen Found	Roscoe's Maximum at the Temperature	Percentage of Saturation	C.C. per Liter Dissolved Oxygen Found	Roscoe's Maximum at the Temperature	Percentage of Saturation	C.C. per Liter Dissolved Oxygen Found	Roscoe's Maximum at the Temperature	Percentage of Saturation
1.....	14.0	3.17	7.12	44.5	3.12	7.12	43.8	3.16	7.12	44.4
2.....	14.5	3.81	7.04	54.1	3.23	7.04	45.9	3.82	7.04	54.2
3½....	15.5	4.41	6.89	64.0	4.12	6.89	59.8	4.26	6.89	61.8
5.....	14.0	4.64	7.12	68.0	4.70	7.12	66.0	4.42	7.12	62.0
11.....	14.5	5.69	7.04	80.8	5.13	7.04	72.8	4.05	7.04	57.5
25.....	14.5	6.71	7.04	95.3	6.22	7.04	88.3	3.0	7.04	42.6

The liquids deprived of gases have, according to the well-known rule, absorbed the gas (in this case air) very rapidly at first, so that in the first hour about half saturation was reached. Afterwards the absorption was very slow, and was not quite completed, even in those thin layers in 25 hours.

That the boiled sewage behaved in nearly the same way as ordinary water shows the effect of the absence of living organisms.

In the raw sewage the absorption is at first normal, but after 5 hours the consumption of oxygen by fermentations overpowers the absorption from the air, and the amount in solution sinks, till in 25 hours it falls again to half saturation. This shows how rapid is the change when it once starts. Adeney observed that a water of a reservoir contained at 5 feet depth 5.71 c.c. of oxygen per liter, at 20 ft. depth only 2.0, due to bacterial action.

The saturation amount of dissolved oxygen found in the New York saline waters, namely 6 c.c. per liter, is equivalent to 8.6 parts per million of oxygen by weight. If in the Harbor it were reduced to 3 c.c., 4.3 parts per million parts would be abstracted by the combined sewage and drainage. This will correspond to 36 pounds of oxygen for each million U. S. gallons. Hence the total 1,500 million gallons of sewage and drainage will have absorbed from its own volume 54,000 lbs. or 24.1 tons of oxygen. But inasmuch as the water coming down is equal to 18,000 million gallons per 24 hours, and this has been equally denuded of oxygen, the *total* quantity of oxygen absorbed is $\frac{24.1 \times 18000}{1500}$ 289.2 tons, or in other words, the sewage and drainage are mixed with twelve times their volume of river water which it has half robbed of oxygen. To *entirely* replace this deficit would require the oxidizing power of its equivalent (8:35.4), or 1,280 tons of "available chlorine." But such a complete oxidation is not necessary because (1) it is considered that the state of the water in the Harbor is not at present objectionable, and will not become so unless there is a reduction of the dissolved oxygen below the present figure of 3 c.c. per liter and (2) chlorine has a sterilizing action beyond its oxidizing power and produces stable compounds.

Points that I have already noticed are:

(1) The bottom layer of sludge absorbs oxygen very slowly from the mass of water above.

(2) The replacement of oxygen by solution from the atmosphere at the surface is also slow.

(3) These two actions tend to counterbalance one another, so that the loss of dissolved oxygen is essentially due to changes occurring in the *liquid* caused by its organisms living on its organic suspended and dissolved matter.

Obviously, screening, and if possible, sedimentation, will remove the greater part of the suspended matter and reduce the deposition in the Harbor. Subsequent chlorine treatment of the effluent, besides destroying pathogenic organisms, will prevent offensiveness and limit the abundance of such organisms as cause deoxidation. I believe the sludge after fermentation may be discharged under water without offense and pass to the sea along with the natural silt of the river.

At Philadelphia it was found that screened sewage treated with 150 lbs. of dry bleach (chloride of lime) per million gallons, equal to 6 parts per million of available chlorine—or screened and settled sewage treated with 105 lbs. of bleach (4 parts per million available chlorine) was economically disinfected (Report Philadelphia Bureau of Surveys, 1911, pp. 127-128). Calculated on this basis the 1,500 million U. S. gallons of New York sewage and drainage would require in tons per 24 hours (the drainage is here assumed to be brought to the sewers and to need similar treatment):

TABLE XLIV

	Available Chlorine	Chloride of Lime of 33% Strength
For Screened Sewage	27.9	83.7
For Screened and Settled Sewage	19.5	58.6

An estimate of the New York population at 6 millions and the sewage at 800 million gallons gives 133 gallons per head. In England we have about 30 gallons per head—so that the comparative dilution is about one to four, and a less quantity of oxidizer would be required than we have found necessary in England.

Assuming the sewage freed from suspended matters by screening and sedimentation in a septic or Imhof tank we may therefore take one-fourth of 24, the figure I obtained at Guildford, and thus arrive at 6 parts per million as the quantity likely to prove effectual.

Provision for Increase of Population

It is supposed that the present population of 6 millions will increase by 1940 to 9 millions, which will add about one-half to the present effect of the sewage. If the existing position is pronounced satisfactory, it can be kept the same by adding a chlorine agent in progressively increasing amounts to balance the advance of 3 millions in population. Then if we take our previous figures for the quantity of chlorine agent estimated for 6 million people, excluding drainage, this addition would progressively reach by 1940, until the additional volume of sewage to be treated will be 400 million gallons or in tons per 24 hours:

TABLE XLV

Sewage	Available Chlorine	Chlroide of Lime of 33% Strength
Screened	7.4	22.2
Screened and Settled	5.	15.

Calculations show that, in most places, the purification of sewage by means of chlorine would be cheaper than purification by aeration. Now chlorine can be added in the following forms:

A. As chlorine gas, the by-product of electrolytic alkali works. This would only be economical if there happened to be alkali works situated quite close to the proposed sewage treatment works.

B. As bleaching powder, made from the gaseous chlorine by-product of alkali works situated at a distance. These alkali works would probably be at a place where power is cheap, and bleaching powder is the best form in which chlorine can be transported. At New York it would probably be possible to obtain bleaching powder from Niagara where power is very cheap; but it must be remembered that it is necessary to pay freight on the bleaching powder, which consists, only to the extent of about one-third, of active chlorine.

C. As sodium hypochlorite, prepared in New York by the electrolysis of sodium chloride solutions. For this purpose, power derived from coal must be used, and this will be more costly than power from Niagara. At the same time the fact that the substance is prepared on the spot saves the cost of its transport.

As a source of sodium chloride, it would be possible to utilize either—

1. The water obtained from the river at the proposed treatment station, three parts of which contains two parts of sea water, or
2. Solid rock salt obtained from the nearest salt field.

At first sight the former proposal, which utilizes sodium chloride that can be obtained free of charge, would seem the more economical. But this is not necessarily the case. The plant required to make hypochlorites from a dilute chloride solution would have to be, *ceteris paribus*, far larger than a form employing strong solutions. The capital cost and maintenance and depreciation charges would thus be increased, and most processes work actually more efficiently when high concentrations are employed. It is more difficult to fix beforehand the cost of making hypochlorites from sea water since, up to date, most plants have been designed to use solutions containing between 5 and 15 per cent. of sodium chloride. If it were determined to use these strong solutions they could be made by dissolving rocksalt in the river water which already contains some sodium chloride; this would economize rocksalt. The cost of production by processes using solid rocksalt as the source of chlorine would be easier to calculate without special experiments, since there are more data available as to actual working experience in these cases. On the other hand, where the issues are so important, it would be worth while to investigate specially processes using dilute solutions and to consider if these could be further improved.

It would be possible, if accurate information as to the cost of power, salt, bleaching powder and labor in New York were provided, to give a definite opinion as to whether B, C (1) or C (2) would furnish the cheaper means of treating the sewage. It would doubtless be possible for you to find out whether there happens to be any factory on the spot which would be ready to dispose of its surplus chlorine, as such, for treatment of part of the sewage according to proposal A.

TREATMENT BY FORCED AERATION

The report by Colonel Black and Professor Phelps in 1911 draws attention to the benefit of a "short period septic action," with which I agree, but I do not consider that subsequent forced aeration in a deep tank would give the improvement they anticipate. The method has been often previously proposed under the hope of "intensified oxidation," but has not succeeded because atmospheric oxygen dissolves and acts so slowly.

The amount of oxygen forced in artificially at considerable expense can only raise the oxygen content to its solubility of 7 c.c. per liter at any one time, and this would have to be repeated about 12 times to equal the quantity of dissolved oxygen now supplied by the river waters. A million U. S. gallons can only dissolve about .037 ton of oxygen so that the 800 million gallons can take up at one saturation nearly 30 tons.

The report concludes that an air consumption of 0.1 cubic feet per gallon would be sufficient under the above conditions. As air contains about one-fifth of its volume of oxygen, this will be 15 volumes of sewage to 4 volumes of oxygen, and is equivalent to 38 repeated saturations even if the oxygen were completely taken up each time. We have no means of ascertaining how rapid this absorption will be locally—it must certainly take several days, and obviously involves the sewage remaining in the Harbor more than three times longer than it does at present as the rate of absorption gradually becomes slower.

On this estimate 15 liters of sewage would require 4 liters of oxygen equal to 5.72 grams, and 1,000 liters of sewage would need $\frac{1000\times5.72}{15}=381$ grams oxygen. That is, a million grams of sewage corresponds to 381 grams of oxygen, or a million tons of sewage to 381 tons of oxygen.

If 1 ton = 269 U. S. gallons, it is evident that a million tons = 269 million U. S. gallons, and the present 800 million U. S. gallons of sewage per day would require to attain an air-consumption of 0.1 cubic feet per gallon:

$$\frac{381\times800}{269}=1130 \text{ tons of oxygen.}$$

This would be theoretically possible, but would involve four difficulties:

(1) Holding up the sewage for 38 days, or such time as 38 saturations take, including:

(2) Tankage for $38\times800=30{,}400$ million gallons of sewage, or such smaller tankage as would ensure sufficient time for the above absorption to take place.

(3) Power to keep the air continuously bubbling through.

(4) Almost certain nuisance from the smell carried off the sewage by the current of air.

AMOUNT OF THE PRESENT NATURAL AERATION BY RIVER WATER

If the water coming down the Hudson, etc., contains 6 c.c. of oxygen per liter, this will be 8.6 parts per million by weight, corresponding to 8.6 tons of oxygen per million tons of river water. A ton of water being equivalent to 269 U. S. gallons, the proportion is 8.6 tons of oxygen in 269 million U. S. gallons of river water.

The water coming down is 18,000 million U. S. gallons per 24 hours. Therefore the total amount will be in tons:

$$\frac{18.000 \text{ million gallons}\times8.6}{269 \text{ million gallons}}=575 \text{ tons of oxygen brought down per 24 hours by the river waters.}$$

The English Royal Commission (Fifth Report, p. 234) prescribes a maximum absorption of oxygen by a *satisfactory* effluent as 0.5 parts of oxygen by weight per 100,000 parts by weight of effluent in 24 hours, equal to 5 tons of oxygen per million tons of effluent. The 575 tons of oxygen mentioned above would therefore supply $\frac{575}{5} = 115$ million tons of purified English sewage effluent, but we have seen that there is no necessity for demanding such a standard of effluent for these waters.

At present about 100 parts of oxygen per million is required by the sewage or twenty times the amount required by a first-class English effluent, and the 1,500 million gallons of New York sewage and drainage, by absorbing the above quantity of 100 parts of oxygen per million, might rob the rivers of 292 tons, which we have seen is half the total oxygen in the rivers as measured by its present volume and oxygen content.

An average rate at which oxygen is absorbed and consumed has been shown experimentally by Adeney to equal *57.5* c.c. per liter in *24* hours by polluted waters or in 48 hours *66* c.c., which is the quantity of oxygen in *11 times* its volume of saturated water. We know from the quantity of dissolved oxygen in the Hudson that half its oxygen is now robbed by the present sewage, and that the volume ratio is 1 to 25 for the sewage or 1 to 12 including surface water and drainage. If the sewage has now absorbed the whole of the oxygen from 12 times its volume of fully aerated water, this is in fair agreement with Dr. Adeney's experimental figures and shows the futility of aeration unless repeated twelve or more times during the whole of the period of absorption.

I have seen the estimated approximate cost of the works for the disposal of the sewage upon farm land, and for the disposal to sea, and these show capital costs much higher than those for local small sedimentation tanks to remove the solids and for plant for chlorine treatment. It would appear that the saving in the capital charges would more than cover the working expenses of chlorine treatment, even assuming that the working expenses of the former methods are small.

It seems, therefore, desirable that the chlorine treatment should have serious consideration, and I recommend that detailed plans and estimates be prepared on these lines, viz.:

(1) Preliminary screening and sedimentation to produce a non-fermenting sludge which can be discharged into the Harbor waters separately without robbing them of any dissolved oxygen, and

(2) A chlorine treatment of the clarified effluent to such an extent as will ensure the proposed minimum standard of 3 c.c. of dissolved oxygen per liter being maintained throughout the whole of the Harbor waters.

(Signed) Samuel Rideal.

November 7, 1912.

SECTION III

PURIFICATION WHICH CAN BE EFFECTED BY SETTLING BASINS AND A REPORT BY KARL IMHOFF UPON THE USE OF EMSCHER TANKS IN PURIFYING NEW YORK HARBOR

Sedimentation is a standard form of sewage treatment which the Commission has recommended strongly in connection with some of its projects for the preparation of New York's sewage before discharge into the tidal waters. It is the method of treatment proposed for the sewage after collection to the large central stations at Ward's Island, Classon Point, Tallman's Island and the Ocean Outlet Island. Its application locally as a general procedure for the sewage of Manhattan and Brooklyn, preparatory to discharging the effluent into the inner harbor, is a subject which has received much study.

Sedimentation is accomplished in settling basins in which those suspended solids which are capable of subsiding from sewage are deposited when brought to a state of comparative rest. The rate of deposit is such that, to be effective, the capacity of the basins, which are sometimes called tanks, must be sufficient to accommodate the flow for one or two hours. With some types of basin, additional capacity is necessary in order to provide that some may be emptied for cleaning out the deposits.

TYPES OF TANKS

Settling basins are of various types and they are put to different uses according to the composition of the sewage which has to be dealt with, the area and location of the land available, the facility with which the resulting sludge can be disposed of and the condition desired for the sewage, especially with respect to decomposition.

The earliest tanks were large, shallow and rectangular, and they received their sewage at one end and permitted it to flow out at the other. Baffles were occasionally constructed to provide for a uniform rate of flow, and the provisions for applying and withdrawing the sewage were intended to afford the best opportunity for deposition to take place. The tanks were cleaned by drawing off the sewage and sending men with boots and squeegees to force the sludge to the proper outlets. There are many large installations of tanks built upon this principle, some of which are covered and some open. Works built upon this principle are at London and Glasgow.

A more recent type of settling basin gives the tank approximately the form of a ship's hull, the narrower shape and greater depth being intended to favor uniformity of flow and better deposition and the shape of the bottom so facilitating the removal of sludge that little or no hand labor is required.

Still greater provision is afforded for the collection and removal of deposits by making the tanks deep and with conical bottoms. The removal of the deposits is in this case effected by pumping or by the pressure of the overlying sewage and without the necessity of emptying the tanks. The Dortmund and Emscher tanks are of this type. Owing to the fact that deep tanks have but recently been invented, there are few practical examples of them in existence, but many have recently been put under construction and there will soon be numerous installations, some of them of large size.

Sedimentation Period and Efficiency

The period of time provided for the settlement of the suspended solids in sedimentation basins may be many hours, in which event the sewage with its sludge undergoes a putrefactive change known as the septic process. It was once supposed that septic tanks were capable of liquefying all of the suspended matter of sewage, but experience has shown that their capacity in this respect was at first greatly overrated. Few septic tanks have been built for the treatment of large quantities of sewage within recent years.

The use of chemicals in connection with settling basins affords a means of hastening and making more complete the deposition of the solid and semi-solid materials which the sewage contains, but this useful result is accomplished at some expense and with the inconvenience of producing large volumes of sludge.

The efficiency of settling basins depends partly upon the period of time which they afford for the suspended matters to deposit and partly upon the condition of the sewage with respect to freshness. The suspended solids can most readily be removed before the sewage has passed through pumps or been subjected to the comminuting actions which occur in passing long distances through the sewers.

If the period of time afforded for sedimentation is too short, the purification effected will not warrant the cost of the works. Experiment on a comparatively large scale is desirable in order to determine the optimum period to provide. In the absence of definite information, it is necessary to be guided by the experience of such cities as have had occasion to deal with sewage of a composition similar to that for which provision must be made.

Such experiments as the Commission has been able to make with New York's sewage, and such experience as has been gained elsewhere with sewage of similar composition indicates that the optimum period of time to provide for the sedimentation of New York's sewage would be two hours, this allowance to be based on the average rate of dry-weather flow. Under these circumstances, settling basins should be able to remove about 60 per cent. of the suspended solids, of which one-half would be organic matter and capable of putrefaction. By the addition of chemicals, the efficiency could be increased so as to remove 85 per cent. of suspended matter and 50 per cent. of organic matter. As compared with screens, such as experience indicates could be employed in New York without undue refinement and difficulty with operating details, sedimentation would be about four times as effective as screening.

One advantage of chemical precipitation lies in the fact that it can be discontinued at any time and a saving in cost of operation effected when weather or other conditions make the use of so efficient a process unnecessary.

Settling basins, like screens, are commonly referred to as preliminary processes of sewage treatment in reference to their ability to prepare sewage for application to percolating filters, contact beds and other finishing processes. Unless followed by some oxidizing process, such as is afforded by sprinkling filters or contact beds, settling basins leave the largest part of the work of purification to fall upon the natural body of water into which the effluent is discharged.

Of the removal of 60 per cent. of the suspended solid matter in the sewage containing 30 per cent. of the total organic matter about two-thirds is probably capable of making an appreciable demand upon the dissolved oxygen, leaving 80 per cent. of the organic matter originally present in the sewage to be discharged in the effluent. Settling basins providing for a two hours' sedimentation period for the sewage of New York could alone not be expected to reduce the demand which the sewage would make upon the dissolved oxygen in the harbor by more than about 20 per cent.

However insufficient settling basins may appear to be when regarded from the standpoint of the oxygen demand, they represent the most efficient process of sewage treatment which can be installed on a very large scale within the limits of New York City. Greater efficiency could only be provided by sprinkling filters or contact beds, and either of these would require excessively large areas of land and be certain to cause offensive odors during warm weather. It is the opinion of the Commission and that of all of its experts who have given careful consideration to the subject that sprinkling filters should not be employed anywhere within the city limits unless under exceptional conditions and in locations comparatively remote from residences and business places.

Disposition of Sludge and the Emscher Tank

One of the principal difficulties connected with the operation of settling tanks has hitherto been the necessity for disposing of their sludge. This material, a liquid black mud, consists partly of colloidal material which parts with its water only with difficulty and is susceptible of offensive decomposition under warm weather conditions. The disposition of the sludge has long been regarded as the most troublesome problem in the entire field of sewage purification. This difficulty is greatest in crowded inland cities; it is least in seaboard cities for these can pump the sludge into tank steamers and carry it to the open ocean for disposal. London, Glasgow, Manchester, Salford and Dublin dispose of their sludge in this manner.

The Emscher tank is provided with a hopper bottom where the suspended solids of the sewage may settle and ferment without producing offensive odors or injuriously affecting the overlying sewage. By fermentation, the sludge becomes diminished in bulk and is reduced to a state in which it readily parts with its water when spread upon suitable drying beds. The tank is the invention of Dr. Karl Imhoff, of Essen, Germany, who holds patents for it in all the principal countries of the world.

Recently introduced in the Emscher drainage district of Germany as a means of removing a large part of the suspended matters from sewage preparatory to discharging it into a system of long, open drains which eventually empty into the Rhine below Cologne, the Imhoff tank has rapidly gained favor among engineers, and numerous plants operating upon this principle, most of them in connection with sprinkling filters, have been put under construction within the last four years.

The Commission has given serious consideration to the use of Emscher tanks as a means of preparing the sewage of New York for local discharge and for discharge from centrally located points, such as Ward's Island and the ocean island. Desiring to obtain an authoritative opinion upon their use, and believing that the arguments which might be put forward in their favor by an advocate would contain the most favorable statements which could be made in comparison with other forms of sedimentation, the Commission, in 1912, requested Dr. Imhoff to make a report upon his invention as applicable to New York.

Karl Imhoff, Doctor of Engineering, of Essen, Germany, is an engineer of high standing both in his native country and abroad. Formerly connected with the Royal Prussian Water and Sewage Testing Station at Berlin, he has for some years been Engineer of Sewage Disposal of the Emscher District Drainage Board of Germany.

In preparation for his report, Dr. Imhoff made an inspection of the harbor on September 30, 1912; an earlier inspection was made by him on May 26, 1911. Various conferences with members of the Commission and its staff, the examination of the Commission's reports and some familiarity with American conditions gained on four short trips to America in the years 1909 to 1912 constituted Dr. Imhoff's preparation for his work.

As a basis for his report, a series of questions was placed by the Commission before Dr. Imhoff. He was requested to express an opinion as to whether Emscher tank treatment was sufficient to bring about the standard of cleanness for the harbor which the Commission proposed in its report of August, 1912; how and where Emscher tanks could be installed in the New York territory and, if Emscher tanks were not sufficient to accomplish the desired results, what other process should be combined with them.

Synopsis of Dr. Imhoff's Report

Dr. Imhoff's report states that the suggestions made as to the practicability of constructing Emscher tanks in the built-up parts of New York and the use of chemicals are based upon assumptions and might have to be materially modified by local conditions. He says the question whether it would be feasible to build such works on the shores of the inner harbor depends upon the possibility of acquiring proper sites and upon the cost of land. He disclaims sufficient familiarity with conditions in the metropolitan district to warrant him in giving technical details. He has therefore only given capacity figures, intending that they should be used as a basis for calculation by the Commission.

Dr. Imhoff considers the most difficult provisions of the Commission's standard of cleanness to comply with are those which relate to deposits and to oxygen. He thinks it unavoidable that deposits somewhat resembling sewage sludge should occur through the death and decomposition of plankton which he says cannot thrive in the mixture of ocean and upland water which exists. Owing to the fact that sea water has a precipitating action upon all suspended matter and because of the unfavorable conditions for the plankton, the harbor is not regarded by Dr. Imhoff as affording favorable conditions for the assimilation of sewage. He agrees with Dr. Adeney that it is the sewage sludge which produces the intense nuisance which exists in places and not the liquid part of the sewage. The average figures for dissolved oxygen are not, in Dr. Imhoff's opinion, capable of indicating the presence of offensive conditions due to the fermenting sludge.

As to efficiency, Dr. Imhoff does not consider that Emscher tanks are capable of satisfying the Commission's standard either with respect to dissolved oxygen or to the deposit of sewage matters in the vicinity of sewer outfalls, but all the other requirements of the standard can easily be complied with. It is impossible for him to say how much sludge can be held back by tank treatment; he is inclined to consider the probable amount about one-half. He thinks that which would be retained would be more objectionable than that which escaped into the harbor.

If Emscher tanks were not sufficient, their efficiency might be augmented by the addition of chemicals. The effect would be to remove practically all the suspended matter and much of the colloid matter. More sludge would be produced and this, Dr. Imhoff says, would require that the sludge chamber in the tanks be increased about 70 per cent. above the size required for plain sedimentation. The report states that Emscher tanks are capable of reducing the volume of sludge, even when chemicals are used.

Dr. Imhoff is of the opinion that, if chemicals were used, that part of the Commission's standard which refers to deposits could be practically satisfied, but it is doubtful whether the reference to oxygen could be complied with.

In the outlying districts of the city, Emscher tanks could, in Dr. Imhoff's opinion, be advantageously combined with percolating filters. In the city limits, filters of this type would not be admissible because of the large areas required and the nuisance from odors and flies which would be practically certain to arise from them. Chemical treatment combined with Emscher tanks is recommended by Dr. Imhoff as an alternative to sedimentation combined with percolating filters for such situations as are suitable for them. The plants which he proposes would consist of Emscher tanks with the application of precipitating chemicals, aeration and rapid filtration. This process, Dr. Imhoff states, would be cheaper and require less area than percolating filters. In winter, when the best treatment procurable was not needed, it would not be necessary to employ the chemicals, thereby saving a considerable amount of money over percolating filters which would represent a considerable investment.

In Dr. Imhoff's opinion, Emscher tanks can be installed in the built-up parts of the city. For local use, he says they should be placed at the mouths of the sewer outfalls, suitably grouped by means of intercepting sewers so as to produce a minimum total cost for Emscher tank treatment. The tanks could be built, in his opinion, beneath the streets or in other open spaces and covered like the subways so as not to interfere with traffic overhead. Sludge pipes would carry the sewage by pumping to steamers at the water front which, after receiving the sludge, would carry it to the ocean for final disposal. Tanks built beneath the streets would not give rise to nuisance, the report says, because little odor would be produced and the gases could be taken care of by ventilation.

Assuming 700 million gallons per day as the quantity of sewage to be dealt with and that one-eighteenth of the daily flow would run off in one hour, the cubic space which should be provided for settling basins on the Imhoff tank principle would be about 10,000,000 cubic feet if it was intended to provide for one hour's period for sedimentation without chemicals. The amount of sludge produced would be about 1,330 cubic yards per day. If chemicals were to be added to facilitate deposition, the sludge digesting chambers would have to be larger than for plain sedimentation. Instead of allowing 4,200,000 cubic feet as Dr.Imhoff advises that 7,000,000 cubic feet be provided.

COMMENTS BY THE COMMISSION ON DR. IMHOFF'S REPORT

It will be observed that the sedimentation period provided for by Dr. Imhoff in his estimates is one hour instead of two, which most authorities regard as the optimum. The Commission considers that 50 per cent. is a rather large removal of suspended matter to expect for settling basins operating with a one-hour period. In this connection, it must be remembered that the supply of sewage is not uniform and that there are times when the flow is so much greater than the average that the settling period in basins intended to provide for one hour would be much reduced. Exceptionally large amounts of suspended matter would be likely to be brought down by the sewage when the flow was greatest, in consequence of which it is possible that considerably more deposit-forming material would be carried through the settling basins into the harbor than might be expected.

The Commission is in favor of chemical precipitation for those situations such as Wards Island, where the purification effected by plain sedimentation may in time not prove sufficient, and where sufficient protection to the harbor can be effected by settling the sewage more thoroughly.

The assumption that the sewage deposits in the harbor do not make a material effect upon the dissolved oxygen is not in accordance with the Commission's opinion nor with that of most other investigators of the New York problem. It is true that the amount of dissolved oxygen present in any large section of the harbor does not afford an infallible indication of the local nuisance which may occur from fermenting sludge. But the evolution of gas carries particles of the putrefying sludge into the overlying water and these particles possess a strong avidity for oxygen which makes itself felt not only where the bubbling occurs but elsewhere by diffusion.

The water of New York harbor is not unfavorable to plankton, so far as the Commission's knowledge of the facts extends. The average percentage of upland water in Upper New York bay and the Lower East river is between 30 and 40 per cent., or roughly, the inner harbor is two-thirds as salt as the open ocean. If minute animals and plants which are natural to the sea are destroyed by upland water, and if upland fauna and flora are killed when they come into contact with sea water, there is no evidence to suppose that such a fatal zone of change lies in the harbor of New York. The Commission's observations indicate that plankton grow abundantly in these waters. See the results of microscopic examinations of river and harbor sediments showing living animal and vegetable forms in the Commission's report of April, 1910, Part III, Chapter IX, pp. 419-421; the rapid rate at which solids were digested through these agencies, in the same report, Part III, Chapter X, p. 461-462; the location and extent of the shellfish whose food consists of plankton, in the same report, Chapter XI, Section II, pp. 472-476. The numerous analyses which have been made show that the putrefying deposits are largely due to sewage. See the Commission's report of August, 1912, Part III, Chapter I, pp. 171-223.

After giving careful consideration to Dr. Imhoff's report and making various studies for such works in various locations, the Commission is compelled to state that, in its opinion, the suggestion that Emscher settling basins could be located in the built-up parts of the city would not be satisfactory. They would not be satisfactory because of their cost, probability of nuisance, and the practical certainty of public opposition. The relatively small efficiency which could be accomplished by them would not be commensurate with the cost of construction and maintenance. These statements apply to Emscher tanks and all other settling basins operating on the principle of plain sedimentation and they have equal reference to tanks operated on the principle of chemical precipitation.

Tentative plans for the construction of Emscher tanks beneath the city streets had been prepared by the Commission before Dr. Imhoff's report was made and his report states that he examined these plans and regarded them favorably. Since these plans represent what was intended to be a practical application of the idea of systematic treatment of New York's sewage by locally placed sedimentation basins and represent in many respects the provisions which might be made for treating the sewage by sedimentation in Dortmund tanks for local discharge, they will be described here at some length.

The plans provided for a plant of 8 Emscher tanks having a capacity of 12,000,000 gallons per 24 hours, with a settling period of one hour. They would be located beneath a marginal street bordering the Hudson river or Lower East river. The principle was sedimentation without the use of chemicals.

The tanks were circular in plan, 35 feet outside diameter and arranged closely together in a single row which took up a large part of the space available between the sidewalk curbing on the one side and the bulkhead of the marginal street on the other. A pumping plant operated by direct-connected electric motors carried the sewage away from the works for discharge by means of submerged outlets or otherwise. The settling basins were protected by means of a coarse screen, simple grit chamber and automatic gate to prevent flooding. Blowers and air ducts were to be used in order to carry away the gases and water-saturated air from above the tanks; inlets were arranged for the supply of fresh air.

The tanks were to be 35 feet deep from the surface of the sewage to the extreme bottom. There was to be a space of 12 feet between the sewage and the top of the street paving overhead, the total depth of construction beneath the street pavement thus amounting to 47 feet. The total length of the plant was 343 feet.

The sewage would be supplied through interceptors which would run along the water front to collect the sewage from the common sewers which otherwise would discharge into the harbor. Provision would be made for sending storm water in excess of the capacity of the plant direct to the harbor and tide gates would be provided to keep the harbor waters from backing up past this overflow. The sewage would enter at one end of the plant, pass through the coarse screen and grit chamber and thence to the tanks by means of a channel running along one side of the row of 8 tanks. After passing through the settling tanks, the effluent would be collected in a channel lying alongside of the tanks parallel to the channel supplying the raw sewage and would flow to the pumps. The sludge would be retained until it was thoroughly decomposed by fermentative action. It would then be removed by the hydrostatic pressure of the overlying sewage to a sump well, whence it would be forced to a tank ship lying at a neighboring pier. The screenings would be removed in the same vessel.

As the construction of the tanks would be close to the water front and largely in made ground, permitting percolation under a considerable head to the lower portion of the work, the method of construction to be adopted is a matter of importance. Two possible methods are suggested:

By one plan the cylindrical concrete curbing or shell would be provided with a cutting edge at the base and constructed in the upper few feet of the pit and above ground. This would be sunk by excavation inside, the shell sinking by its own weight or, if necessary, by an added load on top. Being, by its density, practically impervious, percolation would be cut off except from under the bottom. If this percolation should increase on sinking to such extent as to be unmanageable, it would then be reduced by allowing the pit to partially fill with water and the remainder of the excavation would be done by a clamshell dredge assisted, when necessary, by a diver.

On reaching a point sufficiently below the proposed base of the tank, bags of concrete would be placed over the bottom, serving both to hold the material down and to check percolation. If this were not entirely effective, grout could be pumped through holes to the underlying material. The pit would then be pumped out and the finished bottom laid.

By the other plan the work would be started as before, but provision would be made for the insertion of a strong, watertight, timber bulkhead with air-lock before reaching a point where the removal of water became difficult. From this point on the work would continue under compressed air, as customary in caisson work.

In the completed tank, 35 feet in diameter and extending to a depth of over 40 feet below extreme high tides, there would be an upward thrust on the base of some 1,350 tons. To prevent floatation, this would be overcome by the weight of the structure and the skin friction on the sides. The weight of the concrete work as designed would be about 1,000 tons and that of the steel, earth and paving in the roof and street surface about 200 tons, leaving 150 tons to be overcome by skin friction or about 70 pounds per square foot of exposed surface. If the margin of safety should not be considered sufficient for this (1) the thickness of the curbing could be increased sufficiently to give the added weight required (from 18 inches to not over 24 inches) or, (2) the empty tank could be so connected to the adjacent tanks filled with sewage as to be held in position by the latter. This could be effected by constructing the series of tanks in contact with each other.

In order to provide head room for operation the roof covering the tank chamber is placed close to the street surface and is as shallow as practicable. In the estimates this is composed of 24-inch I-beams spaced 27 inches center to center, with bent plates between to support the street surface without jack arches, which would add considerable weight to the load. Further study would probably indicate some more economical design that would be equally serviceable for this, such as the use of deeper built girders with buckled plates between, but the estimate is believed to be safe.

The estimated cost of construction is:		
For Emscher Tank Plant	$220,000	
For Outlet in Deep Water	14,200	
Total		$234,200
The estimated annual charges are:		
For Operation	$13,250	
For Fixed Charges	12,850	
Total		$26,100

The total volume of sewage to be expected from the Lower East river, Hudson and Bay Division, not far from 1960, and the number of 12 mgd. plants required may be determined as follows:

		Volume of Sewage mgd.*		Number of Emscher Tank Plants	
Manhattan:	Hudson river	255		22	
	East river	193		16	
			448		38
Queens:	East river		75		6
Brooklyn:	East river	240		20	
	Buttermilk channel	18		2	
	Upper bay	105		9	
			363		31
Total			886		75

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*Million Gallons per 24 hours.

It is possible that in some places an Emscher tank plant could be constructed without pumps, thereby effecting a considerable saving, both in first cost and in maintenance charges. Where, however, the effect of the tide would be felt in sewers at the site of the plant, it would be necessary either to exclude the harbor water by tide gates and pump the sewage, or so construct the works as to act without reference to the tidal levels.

Since a large part of the water front of Manhattan is at so low an elevation that the sewers lying but a few feet beneath the surface are tide-locked for 500 feet or more inland, there is poor opportunity for building Emscher tanks without excluding the tide water. Provision of head room, amounting preferably to about 12 feet above the sewage, would be impossible in most cases if the tanks were to be located upon the marginal streets. It is not clear whether Emscher tanks, unprotected from tidal influence, would operate satisfactorily even if the structural difficulties, due to want of head room, height of ground water and crowded space, could be overcome. The average period of sedimentation would be short and irregular, due to the alternate backing up and outflow of the sewage under the action of the tidal head.

The tanks might be built at a sufficient distance back from the water front to be free from interference by the tides, but this would require the reconstruction of the common sewerage system throughout that part of the city which lay between the tanks and the water front. Another difficulty to be overcome, and a more serious one, would be found in the fact that the streets beneath the surface are already occupied with water and steam pipes and conduits for electric light, telegraph, telephone and power purposes. The Emscher tanks would have to be arranged in single file and, for a plant of moderate size, the length of street appropriated would be more than one block long. A plant to deal with 20,000,000 gallons would be about 570 feet long if the period for sedimentation was to be one hour and about 1,100 feet long, or more than one-fifth of a mile, if the sedimentation period provided was two hours. To deal with all the sewage which will be produced by Manhattan Island in 1940, an aggregate of about 3½ miles of tanks would be required, if the sedimentation period was one hour, and about 7 miles, if this period was two hours.

Serious question might be raised, in the Commission's opinion, as to the probability of trouble from the gas given off in the fermentation of sludge in Emscher tanks when placed in crowded positions beneath the city's streets. The odors might not be offensive, although this is not certain, but large volumes of inflammable gas would be produced and this, when mixed with air in the confined space beneath the street pavements, might lead to explosions.

Private property might be acquired, either by purchase or by condemnation, to serve as sites for Emscher tank installations, and, if this were done, some of the difficulties, especially those which relate to crowding, want of ventilation and inconveniently long collections of tanks, could, in large measure, be overcome. Settling basins so located would not reduce the chance of nuisance nor the public protest which might reasonably be expected against them, nor would they add to the ability of the works to purify the sewage, and the cost of the land would add to the expense.

There is no precedent, so far as the Commission is aware, for such extensive underground sewage treatment works as are here discussed. No city seems to have placed settling tanks of large capacity, operating with or without sludge fermenting chambers, beneath the street pavements. No plant of Emscher settling tanks has thus far been constructed to operate with such tidal interference as would be met with (unless avoided by tide gates and pumping) in the most congested sections of the city.

As to the removal of the sludge, Emscher tanks undoubtedly afford one of the best means of overcoming the difficulties of cost of sludge disposal in inland cities. But New York is particularly favored in being close to the sea and so able to ship its sludge to the open ocean at less cost than any other method of disposal. Whether it would be feasible to transport fermented sludge, charged as it is with gas, unless special provision for the escape of the gas was made on the ships, appears doubtful.

The comparative value of Emscher tanks and other deep tanks in which sludge is not digested lies in the opportunities which are afforded by Emscher tanks for the fermentation of the sludge and the consequent reduction in its volume. This advantage is gained at the cost of providing a large storage place for the sludge at the bottom of the compartment in which the suspended matter deposits and ferments. In New York the construction of the deep sludge chamber would be very costly. So far as the Commission has been able to cover the point in its studies and estimates, it would appear that the peculiar advantages which the Emscher type of tank affords over the Dortmund are not warranted by the greater cost of the Emscher tanks.

REPORT OF KARL IMHOFF

To the President and Members of the Metropolitan Sewerage Commission of New York.

Gentlemen: The following questions have been put to me by Mr. Soper, President of the Metropolitan Sewerage Commission:

(1) Is Emscher Tank Treatment sufficient to bring about the standard of purity required by the Commission? (Report August 1, 1912, p. 70.)

(2) How and where may Emscher Tanks be installed?

(3) If Emscher Tanks are not sufficient, with what other process should they be combined?

Sources of Information:

"Report of Metropolitan Sewerage Commission, April 30th, 1910."

"Report of Metropolitan Sewerage Commission, August 1st, 1912."

Preliminary Reports of the Metropolitan Sewerage Commission Nos. I, II, III, and IV, dated September, 1911, November, 1911, November, 1911, and July, 1912.

Four short trips to America in the years 1909-1912.

Inspection of New York Harbor May 26th, 1911, in company with Mr. Soper and his first assistant, Mr. John H. Gregory.

A conference, September 30th, 1912, with Mr. Soper regarding the results of investigations made in the preceding year.

Question Number One

Is Emscher Tank Treatment sufficient to bring about the standard of purity required by the Commission?

These standards are as follows:

(1) Garbage, offal or solid matter recognizable as of sewage origin shall not be visible in any of the harbor waters.

(2) Marked discoloration or turbidity, due to sewage or trade wastes, effervescense, oily sleek, odor or deposits shall not occur except perhaps in the immediate vicinity of sewer outfalls, and then only to such an extent and in such places as may be permitted by the authority having jurisdiction over the sanitary condition of the harbor.

(3) The discharge of sewage shall not materially contribute to the formation of deposits injurious to navigation.

(4) Except in the immediate vicinity of docks and piers and sewer outfalls, the dissolved oxygen in the water shall not fall below 3.0 cubic centimeters per liter of water. Near docks and piers there should always be sufficient oxygen in the water to prevent nuisance from odors.

(5) The quality of the water at points suitable for bathing and oyster culture should conform substantially as to bacterial purity to a drinking water standard. It is not practicable to maintain so high a standard in any part of the harbor north of the Narrows, or in the Arthur Kill. In the Lower Bay and elsewhere bathing and the taking of shellfish cannot be considered free from danger within a mile of a sewer outfall.

Of these five standards Nos. 2 and 4 are, so far as this report is concerned, the most vital. They will therefore be considered first.

Standard No. 2 says plainly: "*Deposits* shall not occur except perhaps in the immediate vicinity of sewer outfalls." This is a requirement very difficult to satisfy. Sludge deposits occur in tidal harbors at the mouths of rivers even when there is no discharge of sewage into the harbor. The fine mineral matters held in suspension in every river water, such as, for example, the fine clay particles, settle out rapidly as soon as they reach the brackish water zone, and for this reason deposits of sludge are always found in harbors situated at the junction of land rivers and large salt water bodies. These sludge deposits, however, are different in appearance from ordinary sewage sludge deposits.

Further, the plankton (a term designating, collectively, the minute animal and plant life in a water) of the river water forms deposits at the junction of a river with salt water bodies. As long as this plankton is alive it neither settles nor floats, but remains in suspension due to its life energy. As soon, however, as the fresh water is mixed with salt water, or sea water, the plankton of the fresh water finds itself in an unfavorable environment, dies, settles out and remains as sludge. Again, sea water also contains plankton, but plankton of an altogether different kind. It also dies when fresh water is mixed with its sea water environment. Therefore, in the brackish zone (*i. e.*, that area in which is found a mixture of sea and land waters) there is a continual process of dying off and settling out of plankton of both kinds.

The natural river sludge and this dead plankton sludge, however, do not settle out in a layer of uniform thickness on the bottom of the brackish zone. The tides in this brackish zone are the cause of continually reversing currents, and these currents shift the light sludge about until it finally finds itself in positions where the velocity of currents is sufficiently low to permit of its remaining there. Such positions will, of course, be near shores, on flats which are alternately covered and uncovered with water, and in the wharves and docks. In such places as these the sludge can accumulate in large quantities, and in these sludge accumulations decomposition will take place. Sludge of plankton origin taken from such places is generally black and contains gases of decomposition. Hence it is often difficult to distinguish between it and half decomposed sewage sludge.

In any brackish zone, therefore, sludge deposits occur other than those due to sewage, and are often in appearance similar to sewage sludge. In Standard No. 2 presumably only such deposits are referred to as arise from sewage sludge.

The pollution in sewage consists of:

(1) The suspended matters (such as fecal matters, street washings and kitchen refuse).

(2) Dissolved matters (such as urine, trade liquors, etc.).

(3) Colloidal matters, which are in character between dissolved and suspended matters.

Of these polluting matters the greatest part of the suspended matters forms sludge when the sewage is caused to flow slowly through a tank. If the sewage is permitted to flow into a harbor without tank treatment, as is now the case in New York City, it is certain that at least that portion which settles out in tanks will settle out in the harbor. But when sea water is present sludge forms to a larger extent than this. Not only the larger part, but practically all of the suspended matters settle out, principally due to the influence of the salt water. Even a large part of the colloidal matters may be thrown out from this cause. Of the dissolved matters it is probable that only a very small portion will form sludge, as the formation of sludge from dissolved matters is mainly a result of that which is generally termed self-purification; and there is only a low degree of self-purification in brackish waters. This is because self-purification, so far as the dissolved organic matters are concerned, is mainly brought about by the action of plankton, and, as has been outlined above, brackish water contains only a very small amount of living plankton.

In general, then, it is only the dissolved matters which are carried out to sea before they have a chance to form sludge. Through tank treatment alone, therefore, it is not possible to prevent all deposits of sludge. It is difficult to say how much of the sludge formed under the New York conditions may be held back by tank treatment. I assume, for purposes of estimation, that the quantity may be reduced by half. But it should be kept in mind that the sludge which is held back by tanks is that portion which is most objectionable, and most likely to produce nuisance. In fact, it is problematical whether the remaining portion is at all capable of producing a nuisance under the conditions obtaining in New York Harbor.

From the foregoing it is evident that the above-mentioned part of Standard No. 2 cannot literally be satisfied by tank treatment alone.

Standard No. 4 may be here repeated:

"Except in the immediate vicinity of docks and piers and sewer outfalls, the *dissolved oxygen* in the water shall not fall below 3.0 cubic centimeters per liter of water. Near docks and piers there should always be sufficient oxygen in the water to prevent nuisance from odors."

That is, with 60 per cent. of sea water and 40 per cent. of land water, and an extreme summer temperature of 80° F., there shall always, except near docks and piers and sewer outfalls, be 58 per cent. or more of oxygen saturation.

Referring to Plate "G" of the August 1, 1912, Metropolitan Sewerage Commission Report, which shows the average dissolved oxygen content of samples taken between June 27 and July 28, 1911, the following values are significant:

Middle of Hudson River, opposite W. 42nd Street	58%
Mouth of Hudson River, opposite the Battery, ¼ mile from shore	54%
Middle of East River, opposite Lawrence Point	56%
Middle of Upper East River, opposite College Point	55%
Middle of East River, near Brooklyn Bridge	54%
Upper Bay, 1.25 miles out from 40th St., Brooklyn	59%
Mouth of Harlem River, opposite Willis Avenue Bridge	28%
Middle of Harlem River, opposite Madison Avenue Bridge	35%

None of these samples were taken in the immediate vicinity of sewer outfalls, docks or piers, and it is evident, therefore, that the 58 per cent. limit is reached, and in many cases exceeded, at the present time. The population of New York City for 1910 is estimated at about 4,600,000; for 1940—8,660,000, nearly double. If Emscher tanks are sufficient, therefore, the work they must do is not only to keep the oxygen figure up to 58 per cent. now; they must do more—they must raise the oxygen percentage to such a point above 58 per cent. that the increased pollution passing the tanks, due to the increase in population, will not by 1940 depress it lower than 58 per cent.

I am thoroughly in accord with the opinion expressed by Dr. Adeney that it is the sludge in New York Harbor which causes the nuisance, the evident nuisance, and not the liquid sewage. There is no doubt that local deposits of sludge putrefy and form gases; and that these putrefying sludge masses are at times impelled towards the surface by their gaseous content, mingling intimately with the waters and producing various forms of nuisance. At these points the oxygen content of the water decreases very rapidly, due to the stage of decomposition of the disseminated sludge particles.

If it is desired to base an opinion regarding the intensity of pollution of the harbor upon such occurrences as these then the oxygen content of the water is an approximate index. It should be kept in mind, however, that this is at best merely a *local* index, and that in general the *average* oxygen content of so large a harbor as that of New York is more dependent upon the liquid sewage content than upon the sludge deposits. Since, however, as has been pointed out above, the dissolved organic matters do not cause the evident nuisance, *average* figures of oxygen content are not an index of such nuisance under the conditions prevailing in New York Harbor.

However, the question as to the value of the oxygen content as a pollution index is not within my province to discuss further. I am simply asked whether tank treatment will keep the oxygen content generally in the harbor as high as 3 c.c.'s per liter.

Therefore I am forced to reply literally that since tank treatment can only at best reduce the sludge deposits, and since it is not these sludge deposits which principally affect the average oxygen content, it is not certain that even at the present time tank treatment will satisfy Standard No. 4; and it is much less certain in 1940.

Thus far I have considered only the two difficult requirements.

Standards No. 1 and 3, and that part of Standard No. 2 not concerning itself with "deposits" can be satisfied by tank treatment alone.

Standard No. 5 does not concern itself with the state of pollution of the harbor. It merely, in effect, indicates the distances to which bathing places and shellfish areas shall be removed from sewer outlets.

To sum up, the first question may be answered as follows: Tank treatment is sufficient to bring about the standard of purity required by the Metropolitan Sewerage Commission with the exception of that clause of Standard No. 2 referring to deposits, and of Standard No. 4, referring to the oxygen content. These two requirements, namely, that except in the immediate vicinity of sewer outfalls no deposits shall occur, and the oxygen content shall not fall below 3 c.c.'s per liter, cannot be satisfied by tank treatment alone, especially not in 1940.

QUESTION NUMBER TWO

How and where may Emscher Tanks be installed?

Emscher tanks may be installed either within New York City itself or, if a trunk sewer system is built, outside of the city. The idea of treating the sewage within the city itself is already being considered by the Bureau of Sewers of the Borough of Manhattan, and this Bureau is now, so far as I know, experimenting in one of the tall office buildings of Manhattan with Emscher tank treatment in the cellar of the building itself.

Instead of placing Emscher tanks at the very sources of pollution, however, it is also possible, and in many respects simpler, to place them at the mouths of the sewer outfalls. There are now, for example, 172 outfalls in the Borough of Manhattan. These would, of course be grouped by local interceptors in such a manner as to produce a minimum total cost of tank treatment.

The following figures will give a conception of the total size of plant required. They are computed on the basis of the probable population in 1917:

Population of New York City in 1917 (p. 136, 1910 Report)....	5,400,000
Population Metropolitan District in N. Y. State, but outside N. Y. City, estimated from p. 143, 1910 Report..........	200,000
Total for Met. Dist. N. Y. State in 1917.....................	5,600,000
Sewage Produced in 1917 by Metropolitan Dist. of N. Y. State in gals. per day, computed on a basis of 125 gals. per head per day, 5,600,000 × 125 = ...	700,000,000 gal. per day.
Settling Basin Capacity Required for New York City with a suggested settling period of one hour: Assuming $\frac{1}{18}$ of the daily flow as running off in one hour, we have a necessary settling basin capacity of 700,000,000 ÷ 18 = 38,900,000 U. S. Gals., or in cubic feet 38,900,000 ÷ 7.48 = ...	5,200,000 cubic feet.
Sludge Room Capacity Required, estimated at 0.75 cubic feet per head = 0.75 × 5,600,000 = ...	4,200,000 cubic feet.

From an engineering standpoint it is without doubt possible to construct Emscher tanks at the mouths of the sewer outfalls. The tanks would either be built under the streets or under any open area, and covered so that traffic would not be interfered with, just as in the case of the subways. From these tanks sludge pipes would lead to such places as would make the collection of sludge by sludge steamers most easy and economical. These sludge steamers would collect the sludge from the various plants at proper intervals and transport it either to sea or to any convenient place outside of the city, where the sludge could be dried and used either for land filling purposes or disposed of to farmers. The amount of sludge that will have to be transported in this manner, estimated at 0.17 liters per head per day, would be

0.17 × 5,600,000 = 950,000 liters per day.
or 950,000 ÷ 28.32 = 33,600 cubic feet per day.
or 33,600 ÷ 27 = 1,330 cubic yards per day.

I am not able to give the technical detals of such tanks because I am not sufficiently well acquainted with conditions in the Metropolitan District. The Commission has made a design for such a unit plant. My impression is, from such examination as I was able to make of this design, that it is constructionally feasible. I am also convinced that such a plant would not give rise to nuisance, for but little odor would be produced and the gases could be taken care of by proper ventilation. Further, the pumping of sludge into steamers would not be accompanied by nuisance.

The whole question as to whether it is possible to build such tanks in the city itself depends only upon the possibility of acquiring suitable locations and upon the matter of costs. I am not able, because of my non-acquaintance with local conditions, to estimate how much such plants would cost in New York City. Instead I have given above capacity figures from which local engineers will be able to estimate the costs. The total inside volume of the tanks will be about 10,000,000 cubic feet.

Emscher tanks may, of course, also be used if New York City decides to build a large trunk sewer system and transport the sewage outside of the city. The Commission has already considered the question of using Emscher tanks in such a case and the following estimate of costs is extracted from Appendix "D" of Preliminary Report No. 1:

Land	$4,700,000
Sewers to Barren Island	51,000,000
Pumping Stations	12,140,000
Treatment Works (Emscher Tanks and Percolating Filters)	49,900,000
Outfall Works	5,000,000
	$122,740,000
Engineering and Contingencies, 15%	18,400,000
	$141,150,000

It is not necessary to consider further the details of construction in this case, as these have already been worked out under similar conditions in other American cities.

QUESTION NUMBER THREE

"If Emscher tanks are not sufficient, with what other process should they be combined?"

In case Emscher tanks are not sufficient they may be combined with *percolating filters,* as indicated in the above table, providing the scheme of carrying the sewage outside of the city is adopted. If, however, the city decides to treat its sewage within the city limits it will not be possible to use percolating filters because of the large area required and because of the nuisance through odors and flies. Therefore, if the sewage is treated within the city it is necessary to seek some other method.

I have made clear in my answer to the first question that tanks can at best take out only a portion of the sludge producing elements of the sewage. The effect of tank treatment may be augmented, however, by the *addition of chemicals.* In the past ten years chemical methods of sewage treatment have come much into disfavor. This has been, however, principally due to difficulties with the resulting large volumes of sludge. Recently in the Emscher district of Germany it has been found that not only do Emscher tanks reduce the volume of ordinary sludge, but that they also reduce the volume of sludge resulting from chemical treatment, leaving it practically odorless and easily drainable. It seems to me, from these experiences, that attention might profitably again be focused upon chemical methods.

The application of chemicals to the sewage of New York City, in case it is desired to treat the sewage within the city limits, will be very easy. It will simply be necessary to add the chemical or chemicals to the tank influent. The effect of the chemicals will take place during the passage of the sewage through the tanks. This effect will consist of the removal of that part of the suspended matters not removed by plain sedimentation, and also of practically all of the colloidal matters. As a result of this higher degree of solids removal the sludge remaining in the tanks will, of course, be greater in volume. Therefore, if chemicals are added to the sewage, the tanks will have to be constructed larger than the preceding figures for simple sedimentation. In order to give a conception of the total size of the plants in this case the following figures are given:

	Cubic feet.
Settling Basin Capacity, as before	5,200,000
Sludge Room Capacity 1.25 cubic feet per head per day = 1.25 × 5,600,000 =	7,000,000

Sludge Produced, 0.23 liters per head per day.

$0.23 \times 5{,}600{,}000 = 1{,}290{,}000$ liters, day.

or $1{,}290{,}000 \div 28.32 = 45{,}600$ cubic feet, day.

or $45{,}600 \div 27 = 1{,}690$ cubic yards, day.

These figures are, of course, based upon assumptions, and might be modified by local conditions to a large extent. A large factor will be the kind of chemical used. In the Emscher district much success has followed the use of wastes from the iron industries. I am not able to say what would be the best chemical for New York to use, and experiments will have to be made to determine this, taking into account the relative quantities of sludge produced and the costs involved.

The apparatus necessary for the addition of chemicals will be so simple and take up so little room that it may easily be installed with the tank under the street. Apparatus for the introduction into the sewage of compressed air, which has been found of advantage in some cases of chemical treatment here, may also easily be installed.

If such chemical treatment is combined with the plain tankage there is no doubt that there will be a decided improvement in the effluent. So much so that of the standards not satisfied by simple sedimentation, Standard No. 2, referring to sludge deposits, will practically then be satisfied, mainly because if chemical treatment is used any sedimentation that may take place in the harbor, as a result of the introduction of sewage, will be mainly due to secondary precipitation from the chemicals themselves. Such resulting sludge will, however, be unobjectionable.

It is doubtful whether Standard No. 4, referring to the oxygen content, would be satisfied by chemical methods. This is for the same reasons given in my answer to Question No. 2. With chemical precipitation the amount of liquid sewage introduced into the harbor, which is the factor mainly affecting the average oxygen content, is practically not lessened. I am convinced that there is no known method of sewage treatment which may be applied within the limits of New York City without producing a nuisance, which will satisfy Standard No. 4.

If it is decided to adopt the scheme of carrying the sewage in bulk away from the city to some point on the sea-coast and there purify it to a high degree, such as is intended in the design previously mentioned (Emscher Tanks and Percolating Filters), chemical treatment such as above outlined should earnestly be considered as an alternative. In this case the plant would be arranged about as follows:

Emscher Tanks.
Addition of Chemicals (including Hypochlorite of Lime, if necessary).
Aeration.
Rapid Filtration.

Such a plant would be much cheaper in construction than tanks with trickling filters and demand much less area. Besides, such a plant permits, as necessary, any desired degree of purification. For instance, in those months in which it is not necessary the final treatment may be omitted, and at such times as it is necessary (as in those months when bathing is practiced) a high degree of purification may be obtained. This is a decided advantage over trickling filters, because when these are used the degree of purification attained is not dependent upon the will of the operator, but upon the weather conditions and other non-controllable factors.

KARL IMHOFF.

Essen, Dec. 23, 1912.

SECTION IV

DISCHARGE OF SEWAGE INTO THE HARBORS OF BOSTON AND NEW YORK AND A REPORT BY X. H. GOODNOUGH ON THE CONDITIONS WHICH LED TO THE CONSTRUCTION OF THE MAIN DRAINAGE SYSTEMS OF BOSTON AND VICINITY

For 30 years Boston harbor has been protected from sewage pollution by main drainage works and for nearly half this period many of the cities and towns in its vicinity have been united in a thoroughly coördinated and comprehensive scheme for the sanitary disposal of their sewage.

In 1912 the sewage of about 300,000 persons, in addition to the sewage of Boston, was discharged through three outlets located near enough to the open waters of the sea to insure a disposal of the wastes by tidal action and digestion.

Similarity Between Former Conditions in Boston and Present Conditions in New York

In many respects the history of Boston and its neighboring municipalities is capable of furnishing an instructive object lesson to New York City and up to a certain point the experience of the two cities is remarkably alike. The conditions which led to the construction of the Boston main drainage works were, to a considerable extent, similar to those which exist at the present time in New York. The sewage, discharged locally through numerous outlets into the restricted waters of the inner harbor, caused sludge deposits and other objectionable consequences and the gross pollution of certain natural tributaries of the harbor was so great as to give rise to offensive odors in the summer season. It was impossible to trace individual cases of disease to the polluted water, but prominent physicians declared that no fact was better established by general experience than that foul air was unfavorable to health and gave it as their opinion that changes in the sewerage system of an extended character, costing large sums of money, could alone accomplish practical good.

In New York the sewage problem has been the subject of official investigation for eleven years. The Boston works were also built after a long period of investigation. In 1870 the consulting physicians addressed to the city authorities a remonstrance to the existing conditions, and the Boston Board of Health, established in 1872, constantly urged improvements in their reports. In 1875 a commission of experts was appointed to study the causes of the objectionable conditions and in its report recommended the construction of a system of intercepting sewers to intercept the flow of the numerous sewers discharging into waters around the city and carry it to a single outlet at an island in the outer harbor. The main features of this plan were ultimately adopted in the construction of the Boston main drainage system and this was the beginning of the entire metropolitan works which now exist.

It is worthy of note that like New York various protective measures were first adopted, such as extending the sewers further from shore, and that while these improvements relieved the objectionable conditions for a time, the nuisances soon recurred. It was not until comprehensive works were carried out that substantial and lasting improvement was obtained.

The objectionable conditions which led Boston to build its main drainage works were not confined to that city. In the densely populated cities of Cambridge, Somerville, Chelsea, East Boston, etc., the conditions were much the same and the commission of 1875 considered the whole territory as the proper field for its investigations. In respect to its scope, the Metropolitan Sewerage Commission of New York has also considered conditions outside of New York and in its report of April, 1910, reported equally upon the need of sewage disposal in New Jersey and New York.

Essential Features of the Boston and Metropolitan Works

The City of Boston proceeded to improve its own sewerage conditions in accordance with an act of the Legislature passed in 1876. It took eight years to so far complete the works as to permit sewage to be discharged from the Moon Island Works.*

Following the Boston City Main Drainage, the North Metropolitan Main Drainage works were put into service in 1895 and the South Metropolitan works in 1904. Twenty-four cities and towns now discharge their sewage through these three outlets.

The best method of disposing of the sewage of the North Metropolitan District was made the subject of investigations. Among the systems considered was collection to a central point for treatment by chemical precipitation and discharge into the inner harbor, filtration through sand on an extensive area of marsh land and the separation, collection and treatment of the sewage of each community and discharge into the local water courses. The subject was finally referred to the State Board of Health which in due course recommended the discharge of the sewage continuously into the sea at Deer Island light at the entrance of Boston harbor. The disposal of the South Metropolitan sewage was investigated in 1899 and 1900 and it was decided to discharge it at Peddock's Island, which lies in a portion of the harbor which is unaffected by the sewage from the other main outlets and where strong tidal currents are available.

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*See cut, Boston Main Drainage, Part IV, Chap. II, page 438.

The total quantity of sewage discharged into Boston harbor through the three main drainage outlets is about 200,000,000 gallons per day. At Moon Island, where nearly half the total volume is disposed of, the discharge occurs at the surface of the water during about two hours of the outgoing tide, being held in storage basins for the remainder of the time. At Deer Island and Peddocks Island, each of which receives roughly one-quarter of the total, the sewage is discharged continuously after coarse screening, in one case beneath about 7 feet and in the other beneath about 30 feet of water at low tide. Before discharge the Moon Island sewage passes through deposit sewers, which act as grit chambers and remove some sand, is stored for some hours in the outlet tanks and, in consequence of its age, is somewhat advanced in decomposition; the Deer Island and Peddocks Island sewage is fresher.

The sewage discharged from Moon Island spreads over a wide area, but careful analyses of the water in the vicinity show little trace of it within a few hours after the discharge ceases. Near Deer Island and Peddocks Island little evidence of the sewage can be detected except in the direct line of the sewage flow. No harmful deposits are formed. Odors are often noticeable for a considerable distance from the Moon Island tanks and only in the immediate vicinity of the other outlets.

PRESENT SANITARY CONDITION OF BOSTON HARBOR

The condition of Boston harbor as respects pollution has repeatedly been investigated by the Massachusetts State Board of Health and many instructive reports have been made upon this subject. In no other place have equal facilities existed for the study of the behavior of sewage when discharged into sea water, and by none have sewage disposal problems received more thorough and authoritative investigation than by the Massachusetts State Board of Health. The report here published by Mr. Goodnough, Chief Engineer of the Board, is a valuable digest of the essential facts relating to this important question and was prepared at the Commission's request in order that the experience gained by Boston and the score of cities and towns in its vicinity might be turned to useful account by New York.

All the members of the Metropolitan Sewerage Commission have visited the Boston outfalls and are familiar with the condition of the harbor with respect to absence of visible pollution.

In the summer of 1911 the Commission's floating laboratory was sent to make a study of the dissolved oxygen in the water. The data collected on this expedition have been published in the Commission's Report of August, 1912, pages 372-392. The analyses show that the harbor waters contained very much higher percentages of dissolved oxygen than are found in New York harbor except in certain localities, notably the mouths of the Charles, Mystic and Chelsea rivers, where some sewage outfalls have not yet been connected with the main drainage systems.

Except in the locations mentioned the water of the inner harbor generally contained nearly its saturation value of oxygen and the water of the outer harbor was almost saturated with oxygen except in the immediate vicinity of the three sewer outfalls. Surface samples collected 50, 100 and 500 feet southeast of the Deer Island light, which is very near the point of discharge, contained 92-93 per cent. of oxygen, but samples from greater depths contained 99-100 per cent. The poorest sample collected at the surface within 10 feet of the outlet contained 53 per cent., but a sample from a point 7 feet below was 88 per cent. saturated. These were the poorest of 35 samples taken close to this outlet.

Of 109 samples taken near Peddocks Island outlet, the lowest in oxygen contained 83 per cent. and most held 95 per cent. or more. Many samples taken immediately over the outlet contained about 90 per cent. of dissolved oxygen. These samples contained so much salt water that it was evident the sewage was well diffused before reaching the surface.

Ninety-one samples were taken at and near the Moon Island outlet. Some samples collected from the surface 500 and 1000 feet from the point of outfall contained 68 per cent., others at a mile distant held 75 per cent. and many others contained somewhat more. There was always less oxygen at the surface where the sewage was densest than at points below. Such pollution as was produced in the outer harbor was confined to the surface, so far as the oxygen analyses could determine.

Two facts brought out in the Commission's Boston harbor investigation deserve to be mentioned for their bearing on the disposal of sewage through dilution in Boston and New York. First, the water in Boston harbor was much more salt than is New York harbor water. Whereas Upper New York bay and the Lower East river ordinarily contain equal parts of sea water and land water, only about 6-8 per cent. of the water in Boston harbor is derived from the land. Second, the temperature of the water at Boston was 15.5-19 degrees C., and in the Lower East river 22-23 degrees C. At Boston the temperature and salinity were practically that of the sea water.

REPORT OF X. H. GOODNOUGH

To the President and Members of the Metropolitan Sewerage Commission of New York:

Gentlemen: The sewers of the city of Boston were constructed originally with the object of draining cellars and lands. The contents of privy vaults, and even liquid from them, were excluded, but they received the wastes from kitchen sinks and rain water from roofs and yards. They were built by a private enterprise, but when the city obtained a charter in 1823 one of the first acts of the city government was to assume the control of all existing sewers and to build and care for the new ones.

A general water supply was introduced in 1848, but for many years no waterclosets were connected with the sewers and fecal matters were rigidly excluded from them. As late as 1857 there were only 6,500 waterclosets in use in the city, but after that date they multiplied rapidly and the number reached 100,000 or more in 1885.

The agitation for a better system of sewage disposal appears to have been begun in 1870. Early in that year the consulting physicians of the city of Boston addressed to the city authorities a remonstrance to the then existing sanitary conditions of the city, in which they declared the urgent necessity of a better system of sewerage, stating that it would be a work of time, of great cost, etc. The board of health of the city, established in 1872, beginning with its earliest reports, constantly urged an improvement in the system of sewerage. In their report of 1874 to the City Council the objectionable conditions resulting from a faulty system of sewerage and sewage disposal, are described at length, and from that report the following extract is taken:

> Although in our annual report of 1873, and again in 1874, we called the attention of your honorable body to the great importance of a change in our system of sewerage, we deem it of such vital importance to the health and comfort of the city at large, but more especially to certain portions of it, that we venture again to urge the subject in a special communication.
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> There are several places in which the evil is already so great that we mention them in particular.
>
> First—The old Roxbury canal, crossing under Albany street, near Chester Park.
>
> Second—The Stony brook sewer, discharging upon the Back bay flats.
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> Third—The Muddy brook sewer, between Brookline avenue and Downer street, in Ward 15.
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> Roxbury canal, so called, leads in from the South bay, is about fifty feet wide and two thousand feet long, reaching nearly to Harrison avenue. The tide flows in and out but sluggishly. Into this three or four large sewers pour their contents, and when the tide recedes there is left but very shoal filthy water, through which the foul gases from the putrid bottom can be seen bubbling into the atmosphere. At low tide a considerable portion of this filthy bottom is left bare, giving off the most sickening and even dangerous effluvia into a thickly populated neighborhood. In Northampton street, Chester Park, Springfield street, Harrison avenue, Albany street, and especially at the City Hospital, where there is a daily average of 230 patients who require pure air, the stench from the Roxbury canal is often observed and exceedingly annoying.

The Stony brook sewer, which conveys the sewage of more than half of the former city of Roxbury, of now about thirty thousand inhabitants, terminates at the west side of Parker street, where, at low tide, this immense sewage is left to trickle over the muddy flats, about one hundred acres in extent, to the Charles river beyond. Before this sewage has reached a point where it can diverge from the wharves of the city, it will have traveled more than one-half of the circumference of the city proper, catching at the bridges, wharves and upon the flats in its course.

An order has recently been passed by the City Council to extend the channel of the Stony brook, so as to prevent the discharge of the sewerage upon the flats next Parker street.

In addition to the Stony brook sewer, there are eight others opening into Charles river above Cambridge bridge, which, with their open mouths at low tide discharging their gases into the atmosphere, and their contents into shoal water or upon flats, are doing a great share in making the atmosphere of that part of the city skirting the river and Back bay, at times, absolutely unfit to breathe.

The Muddy brook sewer coming from Brookline is very large, opens under Brookline avenue, near Tremont street, and is then an open sewer in the immediate rear of dwelling-houses between Brookline avenue and Downer street for a distance of 600 feet, and then crosses the avenue again into the town of Brookline. The water in this brook gets very low in summer, leaving but little besides the sewage matter to flow through it. The stench from this is very bad, and the people who live near it justly complain. This sewer ought to be covered at once, for a distance of about 600 feet, to prevent evil results which must inevitably come from its present condition.

The places mentioned, although the worst, are not all to which we invite attention. The city proper, being nearly surrounded by tide water and flats, is to the same extent literally fringed with the open mouths of sewers, discharging their gases into the atmosphere, and their other contents upon the shoals, which are left bare next the sea-wall and under the wharves by the receding tide.

The result is, that at low tide, and especially in summer, about the wharves and skirts of the city, where thousands of the laboring class must work during the day, and many more will resort for a cool breeze in the evening, the air, instead of being pure and cool from the water, as it should be, is polluted and made dangerous by the foul breath of the sewers.

That our prevalent summer diseases are largely influenced by this poisoned atmosphere there can be no sort of doubt.

From the reports of the board of health, the writings of various physicians and the reports of committees of the city council, and especially of a commission of experts appointed in 1875 to study the whole question of the causes of the objectionable conditions, it is possible to determine quite definitely the causes which made necessary the construction of an improved system of sewerage.

In addition to the objectionable conditions caused by the sewer outlets and the method of disposal of the sewage, the sewers themselves were also objectionable, on account of their design, their location and lack of ventilation, and also on account of the faulty method of trapping and ventilating the house drains; but, except as these conditions were aggravated by the method of disposal and the circumstances affecting the sewer outlets, the objectionable conditions resulting from them are separable from those due to the method of disposal of the sewage and need not be considered here.

The commission of 1875, after a careful investigation of the whole subject, recommended the construction of a system of intercepting sewers, to intercept the flow of the numerous sewers discharging into waters around the city and convey it to a single outlet into the harbor, and the main features of this plan were ultimately adopted in the construction of the Boston main drainage system.

The board of health in its report for the year ending April 30, 1878, describes the nuisances caused by sewage and presents a map showing the location of the principal sewer outlets and the areas of flats on which the sewage had accumulated. From these outlets and areas it appears that foul-smelling gases and odors were diffused for long distances in hot weather under certain conditions of the atmosphere. At times a well-defined sewage odor would extend over the whole south and west ends of the city.

> Complaints of bad odors have been made more frequently during the past year than ever before.
>
> They have come from nearly all parts of the city, but especially and seriously from the South and West Ends.
>
> Large territories have been at once, and frequently, enveloped in an atmosphere of stench so strong as to arouse the sleeping, terrify the weak and nauseate and exasperate nearly everybody.
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> It has been noticed more in the evening and by night than during the day, although there is no time in the whole day when it may not come.
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> It visits the rich and the poor alike. It fills the sick-chamber and the office. Distance seems to lend but little protection. It travels in a belt half-way across the city, and at that distance seems to have lost none of its potency, and, although its source is miles away, you feel sure it is directly at your feet. * * *
>
> The sewers and sewage-flats in and about the city furnish nine-tenths of all the stenches complained of.
>
> They are much worse each succeeding year, and, although so loathsome this season, we can but predict that, for several reasons, they will be much worse next year than this.
>
> The accumulation of sewage upon the flats and about the city has been and is rapidly increasing until there is not probably a foot of mud in the river, in the basins, in the docks, or elsewhere, in close proximity to the city, that is not fouled with sewage.

The board closes its report by urgently recommending the construction of a system of sewerage to relieve the nuisances then existing about the city, but as no system was then under way various palliative measures were adopted by extending the sewers, filling some of the objectionable channels and covering some of the more offensive flats. While these improvements relieved the objectionable conditions for a time, subsequent reports show that the nuisances soon recurred.

In the report for 1882-3 appears the following statement:

> It must be apparent, however, to those who have observed at all, as well as to those who are suffering from it, that the further deposit of sewage in Charles river, in the Back Bay, in the South Bay, on the shores of South Boston, in the docks or elsewhere, the stench from which at low tide is almost unbearable, is, to

> say the least, to be deplored. Even at a considerable distance from these places the stench is already so great as at times to awaken persons from sleep, and we cannot doubt that it is directly the cause of considerable sickness.

In addition to the urgent recommendations of the board of health the physicians of the city in numerous hearings urged an improvement in the system of sewage disposal. A few brief quotations from the statements of a few of the prominent physicians will indicate their opinion as to the conditions existing at the time:

> In the presence of an hourly poison such as the air undergoes the death rate cannot fail to be raised and medical measures for the preservation of the public health will have but little effect.
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> My views are that it (*i. e.*, a change in our system of sewerage) is of such necessity and should be of such an extended character that the expenditure of an immense amount of money, say several millions of dollars, can alone accomplish any practical good.
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> It is impossible to cite individual cases of disease which are distinctly owing to bad drainage. I do not know that I ever saw such, but there is no fact better established by general experience than that foul air is unfavorable to health. That the whole atmosphere of the city has through imperfect drainage become at times too foul for endurance is too patent a fact for any one to dispute and should take precedence in the public attention before any other object of public interest.

The original city of Boston was built on a series of hills and had an area of about 700 acres, or a little over a square mile. The grades were steep, and while the older drains were poorly built, they had good grades and, as they received but little sewage, appear to have caused but little trouble. With the growth of the city large areas of land all about it were reclaimed from the sea by filling the flats about the shores, but the reclaimed land was filled to elevations but little above high water, and the streets traversing the filled areas were often not over 7 feet above that elevation. A large proportion of the house basements and cellars in these filled lands were below high water and many of them but from 5 to 7 feet above low-water mark. The house drains in many cases were laid under the cellar floors and with the necessary fall in the drains and sewers the outlets of the sewers were rarely much if any above low water.

As the lands were filled the sewers were extended to new outlets across the filled portions with comparatively slight fall. The average rise and fall of the tide at Boston is 10 feet, and in consequence of the conditions above outlined, the contents of the sewers were dammed back by the tide during the greater part of each twelve hours. To prevent the salt water flowing into them, many of them were provided with tide gates, which closed as the sea rose above the level of the sewage and excluded the tide water. These tide gates also shut in the sewage, and, there being no current, the solid matters were deposited. To afford storage for the accumulated sewage, many of the sewers were built very much larger than would otherwise have been necessary and rectangular shapes were used instead of the curved inverts now almost always employed. As the tide receded, the tide gates opened under ordinary conditions a short time before low water and the sewage escaped, but it almost immediately met the incoming tide and was brought back to form deposits upon the flats and shores about the city.

Of the large amount of sewage which flowed into Stony brook, into the Back Bay, and into South Bay between Boston and South Boston, it is asserted that hardly any was carried away immediately from the vicinity of the dense populations in those sections.

The objectionable conditions complained of about the city of Boston were not confined to that city. In the densely populated cities of Cambridge, Somerville, Chelsea, East Boston, etc., on the north side of the Charles river, the conditions were much the same as about the city of Boston on the south side of the river, and the Commission of 1875 considered both the sewerage of the city of Boston and of the Metropolitan areas north of the city. The city of Boston, however, did not await the action of those cities but proceeded with the construction of its own system under an act passed in 1876, entitled "An Act to empower the city of Boston to lay and maintain a main sewer, discharging at Moon Island in Boston Harbor, and for other purposes." The works were so far completed that the discharge of the sewage of the city at Moon Island was begun January 1, 1884.

Summary

The foregoing review of the conditions existing before the construction of the Boston main drainage system was begun shows that the principal causes which made necessary the construction of a general system of sewage disposal were the following:

1. The great nuisances caused by the deposits of sewage upon the flats along Stony brook, Charles river, the Roxbury canal and the South bay.

2. The nuisances caused by the sewers discharging into the docks and about the wharves where the tidal currents of the harbor were not effective for the dilution and removal of the sewage.

3. The gross pollution of certain local waters, such as Stony brook and the Roxbury canal, portions of the South bay, where the quantity of sewage was so great in proportion to the quantity of water that the entire quantity of water was polluted to such an extent as to become offensive in the summer season.

4. The low level of large areas of filled lands about the city, on which houses had been constructed at so slight an elevation above high tide that much difficulty was experienced from the flooding of cellars and from inefficient operation of the sewers at times of storms and of extraordinary high tides. These objectionable conditions were especially noticeable in the large areas adjoining what was formerly the neck of the peninsula leading from Boston to Roxbury, especially the region bordering the westerly side of South bay, in what is now known as the South End of the city of Boston.

The Boston Main Drainage System, the Purpose for Which It Was Designed and the Results Achieved

The sewers of the city of Boston were all constructed upon the combined plan; that is, they received both the domestic and manufacturing sewage of the city and the water draining from streets, roofs and yards at times of rain. The removal of all the flow in the sewers when increased by rain water or melting snow would have required works of such enormous size as to have been impracticable. It was also impracticable to separate the sewage from the storm water within a reasonable time except at a great and excessive cost.

The plan finally adopted was: To construct a system of intercepting sewers along the margins of the city, to receive the dry weather flow of the existing sewers; a main sewer into which the intercepting sewers discharge, and which, crossing the southerly part of the city, leads to a pumping station, from which the sewage is pumped to a reservoir on Moon Island in the southerly part of the harbor, whence it is discharged into the sea during the first two hours of the outgoing tide. At the times the works were designed the sewage of the city was discharged through seventy or more different outlets about the shores of the harbor and rivers. These sewers were connected with the intercepting sewers by means of connections of sufficient size to carry somewhat more than the ordinary flow of sewage when not increased by rain water or melting snow. The old sewer outlets were retained, however, and whenever the flow of the sewers is increased by rain or melting snow beyond the capacity of the intercepting sewers to remove it, the excess overflows through these outlets.

It was estimated that a large portion of the southerly part of the city could eventually be drained by a gravity sewer alone to some suitable point of outlet in the harbor without the necessity of pumping, but about 12 square miles of the city were too low to be served by such a sewer and the system was made of sufficient size to care for about 15 square miles, so as to allow for its use until the high-level sewer was built. Provision was also made for admitting a rainfall amounting to about one-fourth of an inch an hour over the whole district, and the quantity that would be carried was of course larger in the earlier years of the works and gradually grew less as the capacity of the system was reached. It has now been relieved by the construction of the high-level sewer, so that the quantity of rainfall removed by the system is probably fully as large as the amount originally proposed.

The system was, however, designed to favor the removal of storm water from certain low-lying districts in the southern part of the city, where drainage was poor, as has already been mentioned, and at times of heavy rain the entire drainage—both storm water and sewage—from three or four of these very low districts is cared for by the main drainage system. The favoring of these districts tends to throw a greater proportion of sewage through the overflow outlets of other districts into the waters about the harbor at times of rain than would otherwise be the case, but thus far, except in a very few instances, seriously objectionable conditions have not resulted therefrom.

The Boston main drainage system was completed in 1884 and first operated on January 1 of that year. Connections had already been prepared and by February, 1884, nearly all of the city sewage was diverted from the old outlets to the new outlet at Moon Island.

As elsewhere stated, the main drainage works were designed and built to correct certain evils inherent in the former system of sewerage and especially of sewage disposal. These were: First, the damming up of the common sewers by the tide, by which for much of the time they were converted into stagnant cesspools and the air in them was compressed and to find outlets was driven into house drains and other openings; second, the discharge of sewage on the shores of the city in the immediate vicinity of population, thereby causing nuisances at many points. These nuisances were partly at the wharves and docks, partly from sewage covered flats exposed at low water and partly from the gross pollution of certain local waters, such as Stony brook, Roxbury canal, South bay, etc. Finally, the system was intended to relieve flooding in low portions of the city at times of storm. The results of its working, as regards the removal of the evils above referred to, are summarized as follows:

> The first of these evils has been entirely corrected by the new system. The old sewers now have a continual flow in them, independent of the stage of the tide, as has been ascertained by frequent observations, and also from the testimony of drain-layers, who formerly were only able to enter house-pipes into the sewers when the latter were empty at low tide, but now can make such connections at any time.
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> The new system has also substantially remedied the second evil. From the moment that any of the city sewers was connected with an intercepting sewer, the sewage which had before discharged on the shore of the city was diverted, and has since been conveyed to Moon Island and emptied into the Outer Harbor at that point.
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> It is true that about twenty-four times during the past year, or an average of twice a month, during rain storms and freshets, the amount of water flowing in the sewers has exceeded the capacity of the pumps. At such times the excess has been discharged at the old sewer outlets. But this occasional and temporary discharge of very dilute sewage does not seem to have occasioned any nuisance. Examinations and inquiries concerning the condition of the shores and docks at the sewer outlets have shown that water, once continually foul, has become pure, bad odors have ceased, and fish have returned to places where none had been seen for years. The stenches referred to by the City Board of Health, which formerly, at times, were prevalent over the city, were not noticed during the past year.
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> The attempt to relieve certain low districts, subject to flooding of cellars during rain-storms at high tide, by discriminating in favor of such districts in respect to the interception of stormwater, has met with marked success. No case of flooding in such districts has been reported since the sewers draining them have been connected with the intercepters; and many cellars, which used often to be filled several feet deep with water, are known to have been perfectly dry during the past year.
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> Building the intercepting sewers has also dried cellars in other parts of the city in a way which was not at first anticipated. When land on the shores of the city was reclaimed for building purposes, most of the old walls and wharves were covered up by the new filling. Tide-water followed along any such structures through the ground, and entered cellars lower than high-tide level. The new sewers were generally built along the present margins of the city, and in digging deep trenches for them the old structures found were cut off and removed. The backfilled earth in the trenches forms an impervious dam surrounding the city, beyond which tide-water cannot pass.

The system was, as a whole, admirably adapted, as its workings have shown, for the removal of the nuisances formerly complained of and for the relief from the other objectionable conditions so long a source of annoyance and injury throughout a large part of the city.

METROPOLITAN SEWERAGE SYSTEMS AND REASONS WHICH LED TO THEIR CONSTRUCTION

The Boston main drainage system now drains a territory of about 15 square miles, which will be reduced to about 12 square miles in the future. As already stated, this system was put in operation on January 1, 1884. The North Metropolitan sewerage system is also shown on the accompanying map* and is colored brown. This system was first operated in 1895.

The reasons which led to its construction are much the same as those which lead to the construction of the Boston main drainage system. The sewage of many of the cities, towns and districts, including Cambridge, Somerville, Chelsea, Charlestown and East Boston was discharged at numerous outlets into the local waters and created serious nuisances. Many of the towns further inland had no sewerage systems and, though sewerage was badly needed, it was impracticable to provide outlets which would not be likely to create very objectionable conditions. There was, furthermore, a large number of manufacturing establishments in those districts of kinds which produced large quantities of very foul wastes, among which were numerous tanneries and large slaughter houses and meat-packing establishments.

The investigations as to the best method of disposing of the sewage in this valley extended over several years. Various systems were considered, including the collection of the sewage at some point near the lower end of the valley and its disposal, after chemical precipitation, by discharging it near the mouth of the Mystic River, and a plan for filtering it through sand on an extensive area of marsh land in the towns of Revere and Saugus. The question of treating the sewage of each community separately and discharging it subsequently into local waters was also carefully considered.

The whole matter was finally referred to the State Board of Health in 1887 and all of the various methods of sewage disposal for this district again carefully considered, and its report, submitted to the Legislature in 1889, recommended the discharge of the sewage continuously into the sea at Deer Island Light at the entrance to Boston harbor.

In the lower part of the North Metropolitan district, where sewerage systems were already in existence at the time the Metropolitan system was constructed, the sewers had been built for the most part upon the combined plan and received both sewage and storm water. In making the connections between these sewers and the Metropolitan sewers the same rule was followed as in the case of the Boston main drainage system, *i. e.,* the dry weather flow, together with a certain proportion of the storm water at times of rain, was taken into the sewers and the excess flow at times of storm over the capacity of the Metropolitan sewers was allowed to discharge at the former sewer outlets. In the districts where no sewerage systems were in existence previous to the construction of the Metropolitan system the sewers were built upon the separate plan and storm water rigidly excluded, since it could be discharged into local waters without objection.

SOUTH METROPOLITAN SEWERAGE SYSTEM

The South Metropolitan sewerage system was established in 1899 and comprises the higher parts of the city of Boston south of the area served by the Boston main drainage system, together with the thickly settled portions of the valleys of the Charles and Neponset rivers. Parts of this district had for many years been tributary to the Boston main drainage works, which was designed of sufficient size to serve these districts for several years after its completion. When, however, the Boston main drainage system had become overtaxed by the extra areas that had been made tributary to it, the question of the disposal of the sewage of the higher districts of the Metropolitan areas tributary thereto was the subject of careful investigation in 1899 and 1900, and it was decided to select a separate outlet for the high level sewer in a portion of the harbor where strong currents were available, unaffected by sewage from the other main outlets.

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*Not reproduced. See cut, Part IV, Chap. II, page 438.

The high-level sewer was completed and first operated in 1904, and the sewage which it receives was formerly discharged at Moon Island.

Effect of the Discharge of Sewage at Moon Island

The quantity of sewage discharged at the various main sewer outlets in Boston harbor and the population connected with each is shown approximately in the following table:

	Estimated Population, 1908	Quantity of Sewage Discharged, Gallons per Day	
		1907	1912
Boston main drainage system	400,000	91,000,000	....
North Metropolitan system	500,000	60,000,000	55,700,000
South Metropolitan system	340,000	40,000,000	48,200,000
Total	1,240,000	191,000,000	103,900,000

The quantity of sewage discharged at Moon Island is now about three times as great as the quantity discharged in the first year after the completion of the works, when the amount was about 30,000,000 gallons per day on an average, though in dry weather the flow was less than that amount and in wet weather was sometimes more than twice the average quantity. The daily quantity of sewage discharged at Moon Island amounted to over 60,000,000 gallons in 1891 and rose to over 100,000,000 gallons shortly before the completion of the high-level sewer.

The quantity of sewage discharged at the Deer Island outlet in 1899—five years after the completion of the works—amounted to about 48,000,000 gallons. The quantity discharged at the high-level sewer outlet in 1905—the first year after its completion—amounted to 25,000,000 gallons per day and in 1906 to 33,000,000 gallons.

The first observations of the results of the discharge of sewage at Moon Island were made by the engineer in charge of the main drainage works about 15 months after the operation of the system was begun. At that time the sewage was stored for about 10 hours and the discharge was begun about 1 hour after the beginning of the ebb tide. At this time the surface of the sea was as low as the bottom of the reservoir and a good harbor current was setting outward past the outlet. A description of those observations is as follows:

> The first sewage which discharges at the outlet contains a considerable amount of sludge which has settled in the gallery and discharge sewers, and gives to the effluent a dark, muddy appearance. After a few minutes the color is somewhat lost, and the effluent looks like moderately dirty water.

> Its effect in discoloring the salt water, and its course as it joins the current out of the harbor, can be plainly noticed. Being fresh water it rises to the surface, and when a half-mile from the outlet seems to lie on top of the salt water in a stratum but a few inches thick. The greasy nature of the sewage tends to quiet the ripples commonly seen on the surface of the harbor, so that the area affected by the discharge is plainly determined. From experiments with floats it is known that the sewage travels nearly five miles, following the Western Way and Black-Rock Channel out to the vicinity of the Brewster Islands. By the time it has traveled a mile from the outlet most of the color is lost, and by the time it has gone two miles (before passing Rainsford Island) not the slightest trace of it can be distinguished.

The only objectionable condition found on the shores about the outlet appears to have been in a small cove or angle between the pier containing the discharge sewers and the shore of the island, where sludge from the sewage deposited and gave off an objectional odor at times of low tide.

The storage reservoirs were enlarged in 1889-1900, however, and a sea wall was built across the end of the island, running from northeast to southwest, and the outlet is now located at the northeasterly end of the wall. There is a small area exposed at low tide along the foot of this wall, on which sludge accumulates in the summer season, which will be referred to later.

The conditions about the Moon Island outlet were studied soon afterward (1888) by the State Board of Health, in connection with the proposed new sewer outlet for the North Metropolitan district, and a test was made of the discharge of sewage continuously at Moon Island at a rate of about 36,000,000 gallons per day, with a view to determining what effect the discharge would be likely to have at Deer Island. The results of these observations are summarized in the report of the Board as follows:

> At the Moon Island outlet of the Boston Main Drainage System the sewage collected in eleven hours is generally discharged in a body in about half an hour, and no sewage is to be found in the tidal current into which it enters two hours after it leaves the sewer. That we might make observations and reach just conclusions in regard to a stream of sewage discharging continuously, the officers in charge of the Boston Main Drainage Works kindly coöperated with the Board by discharging continuously, on a falling tide, for four hours, about 1,500,000 gallons per hour, the equivalent of 36,000,000 gallons per day, which is the amount estimated to be discharged at Deer Island outlet when the population is between 300,000 and 400,000.
>
> When sailing in the stream of sewage, or on the leeward side of it, from near the outlet of the sewer and for a distance of half a mile along the stream, the odor of the sewage was disagreeable. Continuing in the stream of sewage beyond this distance, the odor was noticeable for a time, but before reaching the distance of three-quarters of a mile from the outlet of the sewer the odor could not be distinguished. At this distance, however, the color of the water was distinctly different from the blue of sea water—it was more opaque and browner. But there was nothing, at this distance, with wind blowing up stream toward the outlet of sewer, either in appearance or odor, that was in the least objectionable. The appearance of the water here was like that in the upper harbor in midstream, between the Cunard wharf and the New York and New England railroad docks.
>
> By the color and stillness of the surface the area containing sewage could be

distinguished for a quarter of a mile farther, or at a distance of one mile from the outlet; but no odor could be distinguished, and there was no disagreeable appearance.

At one mile and a quarter a narrow strip of smooth water and a slightly opaque character of the water—seen only upon very careful examination—indicated an effect from sewage; but at one and a half miles from the outlet no trace of the sewage could be seen, although floats which started with the sewage had gone far beyond.

To present this subject with more definiteness than can be conveyed by recording the observations of individuals, samples of the water taken from the middle of the stream of sewage were subjected to more careful chemical tests, in comparison with the adjacent salt water which was unaffected by this sewage, and with the salt water of the inner harbor.

Samples of the sewage throughout the stream of observable sewage and beyond were taken within eight inches of the surface, after the stream had flowed in nearly the same place for three hours, and were subjected to chemical analysis with the following results:

TABLE XLVI

	Free Ammonia	Albuminoid Ammonia	Sum of Ammonias	Chlorine
Salt water, up stream, from area containing sewage.......	.0056	.0098	.0154	1,675
Salt water, down stream, from area containing sewage.....	.0056	.0095	.0151	1,746
Water, within area containing sewage, at the following distances from outlet:				
400 feet....................................	2.5000	.5310	3.0310	773
1,600 “	.1944	.0636	.2580	1,570
3,200 “	.0416	.0254	.0670	1,621
4,700 “	.0224	.0116	.0340	1,694
6,200 “	.0184	.0156	.0340	1,689
7,200 “	.0136	.0108	.0244	1,687
9,200 “	.0104	.0096	.0200	1,710
Water in mid stream at crossing of North ferry to East Boston..	.0480	.0154	.0634	1,581

From these analyses it appears that in the stream of sewage at four hundred feet from the outlet of the sewer the upper eight inches in depth was about one-half sewage. At 1,600 feet distant it contained about one-eighteenth of its bulk of sewage, and at 3,200 feet, or five-eighths of a mile distant from the outlet of the sewer, the ammonias indicated the amount of sewage added to be but 1 per cent. of the volume of the water, and the same amount as found in midstream at the crossing of North Ferry to East Boston. Beyond this distance the amount of ammonia added became about one-half of 1 per cent. at a mile, and less than one-tenth of 1 per cent. at one and four-fifth miles from the outlet.

These results confirm those of direct observation. With the ordinary wave motion at this place, a mile from the outlet, the amount of sewage remaining near the surface of the water is so small that no disagreeable appearance or odor can be recognized.

Continued observations were made from time to time of the effect of the discharge of sewage at Moon Island in subsequent years, and a very thorough study was made in 1899 by the Metropolitan Sewerage Commission,* and in 1900 by the State Board of Health. Since 1902 the outlets have been examined annually by the State Board.

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*Of Boston.

RESULTS OF NUMEROUS INVESTIGATIONS OF THE EFFECT OF THE DISCHARGE OF SEWAGE AT THE MOON ISLAND OUTLET

Sewage is discharged from the reservoirs at the Moon Island outlet at about the level of the sea, with a strong initial velocity, and observations show that the sewage advances over the surface of the tidal current at a more rapid rate than the flow of the current. The area covered varies greatly, being greatest on calm days, when it may cover an area of nearly 1,000 acres. Under ordinary conditions the area covered is smaller. The field covered by the discharge is plainly marked on fairly calm days by the thin film of grease which spreads over the surface of the water and which covers a considerably wider area than that in which sewage can be detected. The presence of sewage can be noted by the suspended matter in the water for a distance of one and one-half miles from the outlet, but areas containing small quantities of sewage are sometimes found at greater distances. The area in which the sewage gives the water an objectionable appearance is about one square mile under ordinary conditions, but the objectionable odors due to the sewage are confined to a comparatively small portion of this area. The sewage spreads widely upon the surface of the water, covering it with a layer of sewage, which rapidly grows thinner as the distance from the outlet increases, and except in the neighborhood of the outlet sewage is rarely detectable in samples of water collected 5 feet beneath the surface.

After the discharge has ceased the sewage disappears quite rapidly, its disappearance being observable by the change in the color of the water. These changes take place all over the area and the sewage rapidly breaks up into small fields and occasionally areas containing traces of sewage can be seen for a considerable time after the general sewage tract has become quite thoroughly broken up. Large areas covered by sleek or the thin film of grease sometimes persist for a longer time but frequently do not contain underneath this film enough sewage to be detectable in the water.

No accurate soundings are available to show whether there has been a shoaling of the water around the Moon Island sewer outlet. The sea is very shallow along the sea wall southeast of the outlet and at this point a deposit of sewage sludge occurs in the summer season, which attains a depth of several inches. A small portion of this only is exposed at low water, so that it does not cause a serious nuisance. This deposit is carried away by the heavy northeasterly storms of winter and the bottom becomes quite clean after such storms. Boatmen who navigate these waters state that they have not noticed any soaling of consequence in this region since the sewer outlet was first established. Soundings across the channel between Moon Island and Long Island have shown the presence of mud on the bottom of the harbor in this section and no doubt heavier portions of the sewage settle here before final decomposition, but there is no available record of the character of this bottom before the discharge of sewage was begun. Considering the enormous quantity of sewage matter that has been discharged here in the 25 years since the outlet was first used, it is evident that whatever accumulations may have taken place have been inconsiderable and that the shoaling, if any, takes place so slowly that it is of little practical consequence.

EFFECT OF THE DISCHARGE OF SEWAGE AT DEER ISLAND

The main outlet for the North Metropolitan system of sewers at Deer Island is located in the neighborhood of Deer Island Light at the end of a long sand bar which is uncovered at low tide. The outlet is placed at the level of low water or a little below it, so that it is covered with water at all times and at high tide to a depth of about 10 feet. The tidal current at this outlet reaches a velocity of 4 miles an hour, or about 6 feet per second.

Studies of the discharge of sewage at this outlet have shown that with a flow of about 2,000,000 to 3,000,000 gallons per hour the area covered by sewage on the ebb tide is about 1¼ miles in length and about two -fifths of a mile in width at the widest place, and the area aggregates about 250 acres under average conditions. On the incoming tide sewage flows in the direction of Governor's Island and on still days covers a slightly larger area than on the ebb.

Observations of the number of bacteria in the water show that they diminish with great rapidity as the distance from the outlet increases, and the number found at a distance of a mile from the outlet is about 300 per cubic centimeter. Three thousand feet from the outlet the bacteria in the sewage amounted on one occasion to about 1,800 per cubic centimeter.

The depth of sewage in the water immediately about the outlet reaches 5 feet and the sea water in the neighborhod of this outlet where sewage is densest had been found on one examination to contain about 3 per cent. of sewage. Traces of sewage in this case also were largely confined to the surface of the sea and little trace of it could be found at a depth of a few feet except in the immediate neighborhood of the outfall. The odor about this outlet is much less noticeable than in the neighborhood of the Moon Island outlet, partly, no doubt, because the sewage discharged here is fresher and partly because the quantity of sewage discharged at one time rarely exceeds 3,000,000 gallons per hour, while the quantity discharged at Moon Island amounts to an average of 20,000,000 per hour for periods of two hours twice each day.

THE OUTLET OF THE HIGH-LEVEL SEWER AT PEDDOCK'S ISLAND

The sewage from the high-level sewer, so called, is discharged at two points—one located off the northwesterly shore of Peddock's Island, one mile north of Nut Island, and the other 1,500 feet to the east and nearer Peddock's Island. The outlets are located in the strong current of President Roads, which, during the incoming tide, flows around the southerly end of Peddock's Island into Hingham Bay, and during the outgoing tide flows through President Roads to the sea. The outlets were separated because observations of the discharge of sewage at the other outlets had shown that sewage, when discharged continuously into a strong tidal current, tended to flow in rather a narrow field and for a comparatively short distance, and it was expected that by dividing the flow the sewage would become more quickly diluted when mingled with the large volume of water flowing through this seaway, and would be carried to sea before it could create a nuisance or lodge upon any inhabited shore or at a place where it might be objectionable. It is expected in the future that a much larger quantity of sewage will be discharged at this outlet than is the case at the present time, but the amount now discharged has so little effect upon the water into which it flows that even when the discharge is much larger than the average the sewage can be seen only in a very small field. It has not been necessary to use both outlets at the same time and all of the sewage has thus far been discharged through one outlet, but the outlets are used alternately for periods of several weeks to keep them free of deposits.

The Peddock's Island outlets, in contrast to those previously described, are located in a deep tidal channel, and the depth of water over the outlets is 30 feet at mean low tide and 40 feet at high tide. The sewage rises rapidly through the salt water but is evidently greatly dispersed and diluted before reaching the surface of the sea and is nowhere as dense at the surface of the water as is the case at Moon Island or even at the Deer Island outlet. Not only is the density much less and the sewage already apparently greatly diluted when reaching the surface of the sea, but it also spreads for a much more limited distance. Very little odor of sewage can be detected about this outlet, excepting in its immediate neighborhood, even when discharging sewage at the rate of 2,500,000 gallons per hour.

Comparing the various observations that have thus far been made of the discharge of sewage at the various outlets, it is evident that the sewage discharged at the Peddock's Island outlets disperses much more rapidly than at the Deer Island outlet and is noticeable over a much smaller field. On very calm days the sleek from this outlet sometimes covers a considerable area. The sleek, however, is a very thin film of grease or oil, often noticeable upon the surface of the water after all of the sewage has been dispersed.

SUMMARY OF THE RESULTS OF THE DISCHARGE OF SEWAGE AT THE THREE PRINCIPAL OUTLETS IN BOSTON HARBOR

The conditions affecting the discharge of sewage at the three main outlets in Boston harbor differ widely in the quantity of sewage discharged, the strength of the currents, the location of the outfalls and, to some extent, in the character of the sewage. The sewage discharged at the Moon Island outlet passes on its way from the city through deposit sewers or settling tanks for the removal of sand, subsequently through a long tunnel under Dorchester Bay and is then stored for several hours in open reservoirs on Moon Island before being discharged. The sewage discharged from the North Metropolitan district at Deer Island contains a large proportion of very foul manufacturing wastes, including wastes from slaughter houses, pork packing establishments, tanneries, currying shops, etc., and much of it is pumped twice and a large portion of it three times before reaching the outlet. It is not passed through settling tanks or stored in reservoirs at any point, however, and reaches the outlet in a much fresher state than the sewage discharged at Moon Island. Part of the sewage discharged at Peddock's Island from the high-level sewer flows there by gravity, while a little over half of it is pumped into that sewer from the main sewer of the Charles River valley and this sewage is probably as fresh when it reaches the outlet as that discharged at Deer Island and is less affected by pumping.

The discharge at Moon Island occupies only about two hours on each tide, so that with the present quantity of sewage the sewage flows into the sea at a rate of 20,000,000 to 25,000,000 gallons per hour. The sewage is discharged at the surface of the sea with quite a rapid velocity, so that it tends to spread widely over the surface and doubtless covers a larger area than it would if the outlet were located in a considerable depth of water. At Deer Island sewage is discharged somewhat below the level of low water and this condition evidently offers a better opportunity for dilution than is the case at Moon Island. At Peddock's Island, where the outlets are 30 feet below the level of low tide, it is very evident from inspection that the sewage has become very considerably diluted before reaching the surface of the sea.

The current into which the sewage is discharged at Moon Island at its maximum is less than 2 miles an hour and is usually not much over 1 mile per hour. At Deer Island the maximum current is 4 miles per hour, and a nearly equal maximum is reached at Peddock's Island.

The spread of the sewage at Moon Island over a wide area is evidently principally due to the greater quantity discharged there, as compared, with the other two outlets, to the manner of discharge and to the slackness of the currents.

The sewer outlets in Boston harbor in all cases discharge into tidal currents of a volume many times greater than the amount of sewage which they now receive. Careful analyses of the water over the field covered by sewage at Moon Island show little trace of it within a few hours after the discharge ceases, notwithstanding the fact that this outlet has been in operation for many years. Similarly at Deer Island no deposits of sewage are traceable along the shores about the outlet nor is it possible to detect even by chemical analysis any effect of the sewage on the sea water except in the immediate field in which it flows.

All things considered, the Peddock's Island outlet, judging from the experience up to the present time, will probably be the most satisfactory of those now in use. The chief advantage at this outlet over the outlet at Deer Island appears to be due to the fact that it is located in deep water and that the sewage becomes considerably diluted before it appears at the surface. The volume of the tidal currents at Deer Island and Peddock's Island are much greater than at Moon Island, but at the latter point the volume of the current is very large in proportion to the quantity of sewage, amounting on the ebb between Long and Rainsford islands to more than 70,000 cubic feet per second.

General Effects of the Discharge of Sewage at the Various Outlets

The reservoirs in which the sewage is stored at Moon Island are uncovered and odors from them are noticeable at times for a considerable distance under conditions favorable for their dissemination. They are not serious enough to make it desirable to cover the reservoirs. As stated above, an offensive odor is noticeable when sailing in the field of sewage within half a mile to a mile from the outlet for a time after the discharge has taken place, but within a very short time after the discharge ceases the sewage disappears, and chemical analyses have shown that very little effect of the sewage is traceable in the water after the effect of the discharge has disappeared from sight.

At the Deer Island outlet, where the sewage covers a smaller area, the odors are noticeable only when sailing within a few hundred feet of the outlet.

At Peddock's Island an odor of sewage is noticeable only immediately about the outlet itself.

The results of careful examinations of the shores of the harbor and of the islands therein show no visible trace of the discharge of sewage excepting the grease balls which form in the sewers and when discharged float upon the water, and may be carried by the currents for many miles before they become thoroughly broken up.

The results of observations upon the effect of the discharge of sewage at the various outlets in Boston harbor as herein given are based upon the conditions found in comparatively calm weather in the warmer portion of the year. In storms and at times of high winds the effect of the sewage is much less noticeable than at other times.

Respectfully submitted,

June 11, 1909. X. H. Goodnough.

PART IV

Data Relating to the Protection of the Harbor

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Data Relating to the Protection of the Harbor

CHAPTER I

THE UTILIZATION OF SEWAGE WITH SPECIAL REFERENCE TO THE POSSIBILITY OF DERIVING A FINANCIAL RETURN FROM THE SEWAGE OF NEW YORK CITY

The utilization of sewage is so desirable, yet so little practised, that the Commission has made an inquiry into the subject with the object of bringing together the most important data in regard to it.

The opinion which the Commission has drawn from this study is that, although the present state of science does not warrant New York in seeking to turn its sewage to profitable account, some process may be discovered whereby this end can be accomplished. The most helpful direction in which to look for this result is with the sludge. The works which the Commission recommends are intended to dispose of the sewage without immediate regard to profit, but they are so designed as to provide for utilization in case suitable processes for the accomplishment of this end are ever devised.

The term profit is here used in the customary sense to mean a return in money, or its equivalent, which may be applied to reduce the cost of building and operating such works as may be necessary to dispose of the sewage in a sanitary manner. If by profit is meant such a saving in the cost of purification as can be effected by a proper employment of the forces of nature to absorb and carry off the objectionable materials, the case is different. In this sense the most profitable use of New York's sewage is that which nature provides in the digestive capacity of the harbor water, whereby a large part of the offensive and harmful ingredients of sewage are rendered harmless without cost. There is here a valuable asset which, if it does not produce visible return, is none the less capable of effecting an immense saving to the city over the cost of works whose object it is to purify the sewage.

COMPOSITION OF SEWAGE WITH REFERENCE TO UTILIZATION

It has been impracticable to analyze the sewage produced throughout New York City and it has never appeared to the Commission desirable to do so. The sewage is contributed by the houses and streets through a large number of local sewerage systems, most of which discharge through outlets which are submerged at most stages of the tide. During all stages, the water of the harbor backs up into the sewers, thereby materially affecting the quality of the sewage. The effect produced is complicated. The sewage is not only diluted, but changes are produced in its composition by reason of the salty condition of the harbor water. Owing to the interference produced in the flow of sewage, deposits occur and an opportunity is afforded for decomposition to take place.

The distance from the water front to which the effects of the tide may produce decided alterations in sewage varies with the part of the city under consideration. In some parts of Manhattan and the Bronx, the sewers feel the effects of the tides in the harbor for over a mile from the sewer outlets. It would be impossible to collect samples of sewage near the outlets at any stage of tide which would show the average composition of the sewage through the twenty-four hours, and samples taken at any other point could not be considered as representative of the sewage with which main drainage works would have to deal.

The standard sewage assumed by the Commission is based upon the known composition of the sewage of such other cities as afford reliable data on the composition of their sewage and in which the conditions of residence and manufacture are more or less similar. It is not expected that the standard sewage assumed will actually be met with when main drainage works are constructed, but the basis of this standard sewage being stated, it will be easy to make such changes as may be necessary in the main drainage works in order that they may meet the requirements of sewage which varies from the standard in any important particular.

Origin and Variable Quality of the Mixture. The sewage from the average American city, when fresh, possesses a dirty gray color and gives off a slightly unpleasant and rather musty odor. A large sample is likely to contain small pieces of newspaper and toilet paper and fine particles of suspended matter. Most of the particles will pass through a screen with a mesh of one-eighth of an inch, the largest particles at the surface of the sewage being excluded. The small solid particles are composed partly of fecal matter and paper broken up by friction against the walls of the sewers, but there are many minute pieces of fiber, cloth and other material, obviously of human origin, and a considerable amount of mineral detritus.

It has frequently been remarked that the presence of human excrement produces very little effect upon either the composition or appearance of sewage. Excrement is especially noticeable when sewers are short. Few of the sewers of Manhattan are long and an unusually large amount of solid particles separately recognizable as of human origin reach the outlets.

Upon standing, many of the solid particles of sewage settle out, causing a dirty, dark and somewhat slimy deposit called sludge.

If sewage is allowed to stand for a few hours at ordinary summer temperature, it becomes putrid and this is true whether the suspended matter has been removed or not. If greatly diluted with water or put upon a sufficient area of land, it will not putrefy; in either case, the organic substances are gradually converted into harmless and inoffensive compounds. It is when the natural purifying agencies which are present in soil and water are overtaxed that putrefaction with its offensive odors is produced. All methods of purifying sewage artificially aim to resolve the substances which are capable of putrefaction into stable compounds under conditions which are under control.

The Liquid Portion. The liquid portion of sewage consists not only of water, but of a large number of substances which are present in dissolved and diluted form. The most prominent component of the liquid part of sewage is urine and this, in combined sewers, may have been derived not only from the human population, but from animals, particularly horses, upon the streets and in stables. As appears elsewhere in this report, the urine contains more of the solid matters excreted by human beings in the course of a given interval of time than do the feces.

A part of the liquid matter of sewage consists of extractives of decomposable and, in some cases, decomposing organic matters from kitchens, streets and factories. Some of these extractives, especially those of industrial origin, may present difficulties of peculiarly troublesome nature in the final disposition of the sewage.

In the artificial purification of sewage, it is customary to dispose of the liquid portion by some process of oxidation. In fact this material cannot be finally rendered inert and incapable of producing offensive odors unless it is oxidized.

The Solid Ingredients. Grit constitutes the largest part of the solid matter contained in combined sewage, if weight alone is considered. It is derived chiefly from the surface of the streets and is present in all degrees of fineness from particles of microscopic proportions to sand and fine gravel.

By the solid matters, however, is usually understood the relatively large materials of human origin which make sewage offensive to the senses. In the report of the Commission for April 30, 1910, the solids of sewage are divided into three classes: Those which sink soon after the sewage is discharged into the harbor; those which continue to float after some time on the surface of the water, and those which are long carried in suspension in the bodies of the tidal streams.

It is evident that particles do not always remain in any of these divisions. Many of those which float gradually become broken up and water-soaked and sink beneath the surface of the water and thus pass from the second to the first division or to the third. In the third class are the colloids or semi-solid materials and finely divided particles of suspended matters.

In disposing of sewage by artificial methods, the management of those solid and semi-solid matters which are collectively termed sludge is recognized as of paramount difficulty. In fact the disposal of sewage resolves itself, in the average case, into the separation of sludge and the disposition of the latter. It is comparatively easy to dispose of the liquid part of sewage.

The Gases. Contrary to popular opinion, there is no gas properly termed sewer gas. Aside from the very large amount of moisture which it contains, the air of sewers does not differ materially, so far as analyses indicate, from outside atmospheric air. In fact, sewers which are properly ventilated contain such a large amount of outside air as greatly to modify the composition of such gases as may be attributable to the sewage.

Probably first in importance among the gases contained or produced by sewage is marsh gas, CH_4. Marsh gas or methane is produced when putrefaction takes place; and decomposition, either of the kind termed putrefaction or other, is invariably present in sewage. Aside from the fact that it is a diluting agent which is capable of reducing the amount of oxygen present by mere dilution, marsh gas is not considered objectionable in sewer air. The amount present is very small in sewers which are well ventilated and so constructed as to avoid deposits.

The decomposition of the compounds of carbon, of which the organic matter of sewage is composed, consumes oxygen and gives off carbon dioxide as do the human lungs. The amount of carbon dioxide present in sewer air and in sewage is small and without any effect upon health. It is also without odor. The offensive odors which arise from sewers are sometimes due to ammonium compounds, sometimes to sulphur compounds and sometimes to mould growths on the sewer. The explosions which occasionally take place in some cities are generally due to gasoline fumes or illuminating gas.

Except when in a putrefying condition, there is usually some dissolved oxygen in sewage. In fact, it is desirable that sewage should always contain this gas except where it is liquefying the solid organic particles in order to facilitate final disposition. If sewers are well ventilated and the sewage is kept fresh, the air from them will not be objectionable.

The Mineral and Organic Matters. It is customary to report the analysis of sewage as containing certain amounts of solid matters present in the mineral and in the organic state. By mineral matters is meant such material as silica, iron, calcium and other materials which are in a state which is permanent and incapable of producing offense. The organic matters are distinguished from the mineral substances in that they can, and are likely to, decompose. With the mineral matters, the art of sewage disposal has but little concern. The worst effect which they can produce is to contribute to the formation of deposits injurious to navigation and to interfere with processes for the removal of the organic matters.

The term organic matter is generally employed in a loose and indefinite manner. Strictly speaking, it should include only such substances as contain carbon in more or less loose combination with other chemical elements. Practically organic matter, as determined by analyses, often means such ingredients of sewage as are capable of being driven off by ignition at red or white heat after the total solid materials in sewage have been extracted by evaporation, although it is quite unreasonable to include as organic matter of sewage such volatile mineral matters as carbonates and salts of ammonia. It is misleading to reckon with the decomposable matters, such organic compounds as paper, wood, matches and hair. These substances, except in comminuted form, are not likely to be included in a sewage analysis and yet it must be remembered that from the time sewage is produced to its final disposition, processes of division and sub-division are continually taking place among the solid particles, so that it is impossible, without a microscopic examination, to distinguish between the resistant and non-resistant parts of the organic content.

The Bacteria and Other Forms of Life. As may be inferred from a consideration of the origin of sewage, bacteria and other minute forms of life are usually present in great number and variety. Those of essential importance comprise the infective agents of disease and the bacteria which are concerned in the decomposition of the organic matters. So far as utilizing the sewage is concerned, the bacteria of disease may be excluded from consideration except in so far as the method of disposal may lead to infection as, for example, through drinking water supplies, shellfish, bathing, fishing, the collection of driftwood, or by eating the raw product of farms on which sewage or sludge has been used as a fertilizer.

No process of sewage purification, except disinfection and the application of sewage to land, has thus far been found capable of eliminating disease germs. Most processes of sewage disposal produce but little effect upon the dangerous character of the sewage. Sewage purification is not properly to be regarded as a sufficient means of protecting sources of water supply into which the sewage must eventually be discharged. The necessary protection can, in most cases, be much more suitably and economically effected through the purification of the drinking water than by the purification of the sewage. This does not mean that the sewage of a great city should be discharged into a natural body of water without regard to the harmful bacteria which may be present. Where disposal entails serious risk to health, special precautions in the way of disinfection should be practised.

When bacteria which are capable of producing disease are discharged into sewers, material reduction in the number of the disease germs ordinarily takes place. The popular belief that the harmful bacteria multiply in sewage and in polluted water is unfounded. Laboratory experiment and experience gained in many investigations show that there is little danger to be apprehended by those who may be compelled to work in sewers or in sewage disposal plants because of the germs of disease which may be present.

Where sewage is discharged into natural bodies of water or upon land, the unfavorable conditions which there occur for the continued life of the bacteria soon lead to the elimination of all danger. Epidemics of typhoid and cholera which have been traced to water have been due, in most cases, to relatively recent and intense pollution. Harmful bacteria appear to live much longer in sludge than in the liquid part of sewage.

There seems to be no special risk to health attending any of the processes employed in the utilization of sewage except where gross carelessness exists. Inquiries made in English cities where the conservancy system is employed have failed to show that the employees engaged in collecting or disposing of the excrement are peculiarly prone to disease. The laborers and others who dwell among the sewage irrigation fields of Paris and Berlin enjoy excellent health. It is dangerous to sprinkle fresh sewage upon garden vegetables or fruit and persons who work with sewage should be careful to cleanse their hands thoroughly before eating.

In view of the potential danger which would seem to exist in sewage, it is remarkable that so few epidemics of disease have been attributed to the disposal of sewage by application to land. Aside from a few explosions of typhoid fever, said to have been produced by eating celery, lettuce and watercress, there is little recorded evidence to show that food, other than milk and shellfish, is at all likely to become infected.

The destructive agencies which cause the disappearance of harmful bacteria, when the sewage is discharged upon land or into a natural body of water, are not all understood, but the subject has been investigated sufficiently to show that sunlight, uncongenial temperature and lack of suitable food are among the principal conditions which make for the destruction of pathogenic bacteria. So particular are the requirements of disease germs that there are very few known species which will live and multiply, except for a brief interval, outside of the body.

Natural Changes Which Sewage Matters Undergo in the Presence and Absence of Air. Prominent among the bacteria which must be considered in the disposal of sewage are those which carry on the various forms of decomposition to which sewage is liable. The bacteria in this class find their nutriment in the dead organic matter of sewage as distinguished from disease germs which feed upon a living host.

In the presence of a sufficient supply of oxygen, the bacteria of decomposition are capable of breaking up the complex organic molecules of the solid and liquid substances of sewage and resolve them into harmless inert mineral matters. Among the bacteria of this class are those which attack the ammoniacal matters and produce nitrates and nitrites. These organisms are everywhere present in soil and water. They are indispensible in preventing sewage from producing offensive odors.

Septicization. When the oxygen supply is deficient the bacteria of putrefaction become active and break down the organic compounds, liquefying the solids and producing offensive-smelling gases. At one time it was thought desirable to utilize putrefying bacteria in order to get rid of the solid organic matters and otherwise prepare the sewage for final disposal. The present tendency is to keep the sewage from putrefying and to deal with it in the freshest condition practicable. In the average case, no useful end is to be accomplished by bringing about septic action, as putrefaction is customarily termed. In fact unfavorable conditions due to foul odors brought about by septic action often restrict the application of this process.

In addition to the bacteria, other forms of life in great variety are present in sewage. Not improbably enzymes and other ferments are intimately connected with the phenomena of putrefaction and oxidation. In breaking up solid particles, larger forms than the bacteria are of use. These larger forms comprise representatives from the animal and vegetable kingdoms, such as are commonly present in decomposing matters of any kind. The black color of septic sewage is due to the formation of sulphide of iron probably by bacterial decomposition of sulphates.

The peculiar musty, sweetish odor noticeable in most sewers is generally ascribed to fungus growths. Fungi of many kinds find the conditions of food, temperature and moisture suited to them in sewers, the result being that luxuriant growths often occur.

Composition of the Standard Sewage Assumed for New York. The composition of New York's sewage has been described by the Commission in its report of April 30, 1910, Chapter X, page 429, report of August, 1912, Chapter III, page 28, and preliminary report No. VI, February, 1913, page 19.

The following table gives, without unnecessary detail, and in form convenient for use, the principal ingredients of the standard sewage of the City of New York. This composition is based on the assumption that 100 gallons of sewage are produced per capita per 24 hours.

TABLE XLVII

STANDARD NEW YORK SEWAGE

	Parts by Weight per Million of Water
Solid Matters	800
Dissolved	500
Suspended	300
Organic and Volatile Matters	400
Dissolved	200
Suspended	200
Nitrogenous	150
Nitrogen	15
Non-Nitrogenous	250
Fat, etc.	50
Total Carbon	200

Table XLVIII, prepared from Table XLVII and data contained in the report of this Commission dated February, 1913, pages 18 and 20, gives the quantities in tons of the various ingredients of the sewage calculated in accordance with the foregoing standard composition, the number of gallons per capita of sewage produced and the population producing the sewage as of the years 1910 and 1940.

TABLE XLVIII

WEIGHT OF SEWAGE INGREDIENTS TRIBUTARY TO THE SEVERAL DIVISIONS OF THE HARBOR. THE RESULTS STATED ARE TONS OF 2000 LBS. PER 12 LUNAR HOURS

Division of the Harbor	Suspended Solid Matters	Organic and Volatile Matters						Sewage Mgd.*	Population	Gallons, per Capita per Day
		Total	Dissolved	Suspended	Nitrogenous	Fats, etc.	Carbon			
	1910									
Harlem river	52	70	35	35	26	9	35	99	797,000	124
Hudson river	65	87	43	44	33	11	43	132	1,900,000	131
Upper East river	12	16	8	8	6	2	8	21	182,000	115
Lower East river	133	178	89	89	67	22	89	264	2,058,000	120
Upper bay	34	45	23	22	17	6	23	64	519,000	123
Newark bay	7	9	4	5	3	1	4	13	103,000	126
Kill van Kull	3	4	2	2	2	0.6	2	7	50,000	140
Jamaica bay	23	30	15	15	11	4	15	53	351,000	151
	1940									
Harlem river	111	148	74	74	56	18	74	253	1,708,000	148
Hudson river	126	168	84	84	63	21	84	302	1,940,000	156
Upper East river	43	57	29	28	21	7	29	99	649,000	152
Lower East river	209	279	139	140	105	35	139	454	3,223,000	141
Upper bay	59	79	40	39	30	10	40	118	908,000	130
Newark bay	13	18	9	9	7	2	9	30	200,000	150
Kill van Kull	9	12	6	6	4	2	6	23	139,000	165
Jamaica bay	59	79	39	40	30	10	39	163	909,000	180

*Million gallons per day.

The Question of Utilization.—So far as utilization is concerned, the most valuable ingredients of sewage are nitrogen, phosphoric acid, potash and fat. The following table gives the amounts of these substances, excepting the fat, found in the sewage of the Lawrence, Mass., Experiment Station during 1912, as stated by Mr. H. W. Clark in the Monthly Bulletin of the State Board of Health for December, 1913.

TABLE XLIX

AMOUNT AND VALUE OF THE FERTILIZING CONSTITUENTS IN 100 GALLONS OF LAWRENCE SEWAGE

	Pound	Cents per Pound	Value (Cents)
Nitrogen as free ammonia	.27	16	4.3
Kjeldahl nitrogen	.09	10.0	.9
Phosphoric acid reckoned as P_2O_2	.08	5.0	.4
Potash reckoned as K_2O	.12	4.2	.5

Each thousand gallons also contained about one-quarter of a pound of fatty matters worth, at 3 cents per pound, about 7.5 mills.

Assuming that the composition of Lawrence sewage fairly represented the sewage of New York, the following table has been prepared to show the weight and value of fertilizing ingredients contained in the sewage which is tributary to the several divisions of New York harbor. The Lawrence sewage contained, in parts per million, the following fertilizing ingredients:

Nitrogen as free ammonia	32
Kjeldahl nitrogen	10.8
P_2O_2	10.0
K_2O	15.0

TABLE L

WEIGHT AND VALUE OF FERTILIZING INGREDIENTS CONTAINED IN THE SEWAGE TRIBUTARY TO THE SEVERAL DIVISIONS OF NEW YORK HARBOR

Division of the Harbor	Sewage Mgd.	1910									
		Quantities in Tons of 2,000 Pounds per 24 Hours					Values per 24 Hours				
		Nitrogen as Free Ammonia	Total Nitrogen	P_2O_5	K_2O	Fats	Nitrogen as Free Ammonia	Total Nitrogen	P_2O_5	K_2O	Fats
Harlem river	99	15.04	5.08	4.70	7.08	17.80	$4,812	$1,016	$470	$595	$1,068
Hudson river	132	20.05	6.78	6.27	9.43	23.73	6,420	1,355	627	792	1,424
Upper East river	21	3.19	1.08	0.99	1.50	3.77	1,020	216	99	126	226
Lower East river	246	37.35	12.62	11.68	17.56	44.20	11,950	2,525	1,168	1,475	2,640
Upper bay	64	9.72	3.29	3.04	4.52	11.50	3,110	657	304	380	690
Newark bay	13	1.98	0.67	0.62	0.93	2.34	634	134	62	78	140
Kill van Kull	7	1.06	0.36	0.33	0.50	1.26	339	72	33	42	76
Jamaica bay	53	8.05	2.72	2.51	3.79	9.52	2,576	544	251	318	571
Total	635	96.44	32.60	30.14	45.31	114.32	$30,861	$6,519	$3,014	$3,806	$6,835
Grand Totals, per 24 Hours: Weight, 318.81 Tons; Value, $51,035.							Per Year: Weight, 116,366 Tons; Value, $18,627,775.				

TABLE L—Continued

Division of the Harbor	Sewage Mgd.	1940*									
		Quantities in Tons of 2,000 Pounds per 24 Hours					Values per 24 Hours				
		Nitrogen as Free Ammonia	Total Nitrogen	P_2O_5	K_2O	Fats	Nitrogen as Free Ammonia	Total Nitrogen	P_2O_5	K_2O	Fats
Harlem river.....	253	32.00	10.81	10.05	15.04	37.84	$10,240	$2,162	$1,005	$1,263	$2,270
Hudson river.....	302	38.22	12.90	12.00	17.95	45.17	12,230	2,580	1,200	1,507	2,710
Upper East river.	99	12.52	4.23	3.93	5.88	14.20	4,005	846	393	494	852
Lower East river.	454	57.45	19.40	18.05	27.00	67.90	18,380	3,880	1,805	2,267	4,074
Upper bay.......	118	14.94	5.04	4.68	7.01	17.65	4,780	1,008	468	589	1,065
Newark bay......	30	3.80	1.28	1.19	1.78	4.49	1,216	256	119	149	269
Kill van Kull.....	23	2.91	0.98	0.91	1.37	3.44	931	196	91	115	206
Jamaica bay.....	163	20.62	6.96	6.47	9.69	24.38	6,600	1,392	647	814	1,463
Total........	1,442	182.46	61.60	57.28	85.72	215.07	$58,382	$12,320	$5,728	$7,198	$12,909
Grand Totals, per 24 Hours: Weight, 602.13 Tons; Value, $96,537.							Per Year: Weight, 219,777 Tons; Value, $35,236,005.				

* In making out this table, account has been taken of the greater dilution, 149 gallons per capita instead of 125 gallons, as in 1910. Quantities per million gallons are therefore taken as 125–150 of the same values for 1910.

Any process which is to become effective for the utilization of sewage must comply with the sanitary requirements which may reasonably be prescribed and, in doing so, must answer to a number of demands which are seldom made in the conduct of a successful business enterprise. Prominent among these requirements is the necessity for utilizing the sewage as it comes to the works in spite of the variations in volume and in composition which occur. This variation is reduced to a minimum where the works are located at a long distance from the point of origin of the sewage and where the sewage is a mixture from various sections of the city. Both the long distance traveled and the mixing are likely to serve usefully in counteracting such changes in composition as always occur when the sewage is derived from small areas.

If the works are to utilize all the sewage, it is necessary that they shall be elastic in capacity in order to accommodate themselves to the variations in flow. If the process of utilization is mechanical or chemical in character, the necessary elasticity may often be readily secured, but where the process involves biological action as, for example, application to land, serious embarrassment from the fluctuations may result.

From the composition of sewage, it is evident that of all the constituents normally present, the water and those substances which may be of value to growing plants are likely to be the most useful. The mineral part of the suspended matter, like the forms of life which are present, is only incidental and of no advantage theoretically or practically. Among the useful ingredients, the water is in some cases the most valuable material which sewage contains, but this value exists only in those situations where the land needs water.

Among the plant foods which sewage contains, the nitrogen compounds are the most important.

The recovery of grease, except where the sewage is known to be particularly rich in this ingredient, is not regarded as an economical procedure.

Aside from the application of sewage to farm land, the idea of utilization carries with it the necessity of extracting the useful ingredients in the form of sludge and resolving this into a form in which the solids can conveniently be stored and transported. The presence of the water, overwhelming in volume and resistant by reason of its molecular combination with the fine gelatinous particles of suspended matter, is a problem of peculiar difficulty.

THE NITROGEN PROBLEM

Importance of Nitrogen

The fundamental theory upon which attempts have been made to utilize the manurial ingredients of sewage has been based upon the belief that the nitrogen was worth saving.

Nitrogen is one of the most important elements entering into the food of men and animals. It is a valuable constituent of plant foods and enters largely into the composition of meat. It is thrown off by animals with their excrement and is to some extent returned to the soil from which it is derived.

The term nitrogen specifies nitre-producer and was suggested by the fact that nitrogen is an ingredient of saltpeter which is known among chemists as potassium nitrate. Saltpeter has been employed in various ways for many centuries. It occurs as an efflorescence upon the earth as a result of the oxidation of organic nitrogenous matter in the presence of potash in the soil. It is occasionally found in the neighborhood of villages, more especially in hot climates, where urine and other readily putrescible organic matters rich in nitrogen exist.

Consumption of Nitrogen Compounds in Agriculture and in the Arts

The commercial demand for nitrogen compounds arises chiefly from the requirements of agriculture and certain chemical industries. Some idea of the extent of this demand may be obtained from the fact that the United States sends annually abroad over $32,000,000 for the purchase of nitrogen in various combinations. The principal demand is for the manufacture of fertilizers. Coal-tar dyes to the value of over

$6,000,000 are annually imported into the United States. In addition, indigo in value exceeding $1,000,000 is brought into this country, and nitrogen, for the preparation of explosives, is imported to an extent exceeding $1,000,000. In the year 1910, the imports of crude nitrogen compounds into the United States for various purposes were approximately as shown in Table LI.

TABLE LI

Value of Crude Nitrogen Compounds Imported into the United States in 1910

Sodium nitrate	$16,548,000
Ammonium salts	3,771,000
Guano	820,000
Anilin oil and salts	715,000
Coal-tar dyes	6,016,000
Coal-tar derivatives	800,000
Explosives	1,003,000
Indigo	1,224,000
Potassium nitrate	791,000
Miscellaneous	696,000
Total	$32,384,000

In addition to the foregoing, large quantities of fertilizers are employed in the form of natural manures. Manufactories have recently been erected for the synthetic production of nitrogen compounds and the products of these should be included in estimating the total consumption of fertilizing materials. Finally, in every large city there are places where bones, slaughter-house wastes and offal are rendered into fertilizing materials and the aggregate of their product is not to be neglected.

Main Sources of the Nitrogen Compounds

Most of the nitrogen compounds which are used as manure are derived from certain natural supplies of fixed nitrogen, of which Chili saltpeter is an example, and the fixation of nitrogen from the unlimited supplies of this gas which exist in the atmosphere.

NATURAL SOURCES

Chili Saltpeter. The most important single source of combined nitrogen in the world at the present time is the deposit of sodium nitrate which exists in Chili. These deposits are believed to have been formed by the decomposition of seaweed and marine refuse through favorable conditions of temperature and the activity of nitrifying bacteria.

Saltpeter. Potassium nitrate, or saltpeter, is produced when organic matter, such as urine or excrement, decays through the action of bacteria in the presence of potassium carbonate. It has often been an important source of one of the chief ingredients of gunpowder at times of warfare and up to about one hundred years ago was practically the only source of combined nitrogen available. About 20,000 tons are produced in India, the cost being about $75 per ton.

The natural occurrence of potassium nitrate and its continued formation in certain regions of the world is so slight as to constitute no serious factor in business, but the conditions which are most favorable for the production of these nitrates are worth considering from the standpoint of sewage utilization. There are said to be needed (a) porous earth which will allow easy access of air and water; (b) moisture sufficient to prevent dryness; (c) an abundant supply of decaying organic matter rich in nitrogen; (d) temperatures ranging from 5 to 55 degrees C. with 37 degrees as the most favorable and (e) weak alkalinity of the soil due to the presence of carbonates, potassium, calcium or magnesium.

Guano. Guano is a nitrogenous organic compound which occurs in large natural deposits and is highly valued as a fertilizer. Its value lies not alone in the fact that it contains combined nitrogen, but it possesses a useful amount of phosphoric acid which is one of the most important manurial ingredients. The chief sources of guano are the islands and coasts of tropical and semitropical America, Africa, Oceana, Patagonia and Labrador, and it is said that an island off the Mexican coast, containing a deposit of about 10,000,000 tons, is being operated by an American company. Deposits of guano are made up of the excrement of birds.

Coal. The largest natural supplies of combined nitrogen which exist are contained in deposits of coal. Anthracite coal contains from ½ to 1 per cent. of nitrogen, bituminous coal ½ to 1½ per cent. and brown coal from 1 to 2 per cent. Most of the nitrogen which is contained in coal can be recovered by dry distillation, as in the manufacture of gas, a part being given off as ammonia and another as free nitrogen. If all of the 1,000,000,000 tons of coal annually produced were distilled before it was used as fuel, it would yield at least 50,000,000 tons of pure ammonium sulphate, which has a current market value of over $50.00 per ton. The amount of commercial ammonium sulphate actually secured from coal was about 1,100,000 tons in the year 1910.

Peat and Silt. In addition to the stores in coal, large supplies of combined nitrogen exist in the vegetable matter which is undergoing slow decomposition in various parts of the world in the form of peat and silt. The world's supply of peat is enormous and increasing. At present about 10,000,000 tons are used annually as fuel. Dried peat contains about 1 per cent. of nitrogen and it can be used for fuel in such a way that about three-quarters of this nitrogen can be recovered as ammonium sulphate.

City Refuse. The vegetable and animal refuse of cities, aside from the sewage, is often rich in nitrogen and in some cases this nitrogen can be utilized. The waste of sugar works and distilleries, slaughter houses, as well as of households and markets, contains compounds in which nitrogen exists in various combinations. Much of this nitrogenous refuse is either in a state of decomposition or ready to proceed upon that course. The nitrogen is fixed, but beyond that fact and the circumstance that its complicated chemical combinations can be changed into useful forms, the refuse is of practically no value in agriculture. Before extracting the serviceable ingredients of city refuse, it is necessary to pass it through some such process as dry distillation for the recovery of ammonium sulphate or putrefactive fermentation.

ARTIFICIAL SOURCES

The demand for nitrogen in chemical combinations suitable for use as fertilizer and in the arts has led to the invention of a number of processes for the recovery of nitrogen from the atmosphere and the transformation of this nitrogen into suitable compounds.

All these processes require great heat and this is usually supplied by some form of electric flame. The opportunities for the electric recovery of nitrogen are best in those places where large amounts of electrical power can be obtained cheaply. Works on a large scale exist in Norway, Italy and in America.

Mond Gas. It has been shown practically that a large amount of the nitrogen in coal can be recovered in the form of ammonia in the production of water gas. An essential feature of the process is the introduction of steam superheated to 150° C. into the generators. Fully one-half of the nitrogen present is obtained in the form of ammonia. A short ton of coal is said to yield an average of 6.6 pounds of ammonium sulphate.

The Mond process has spread rapidly in England, where there are 60 plants using over a million tons of coal annually. Of these plants 15 are fit for the collection of ammonia. The yield of sulphate in 1909 was over 26,000 tons. Other plants are located in Germany.

HUMAN EXCREMENT VERSUS OTHER FERTILIZERS

The introduction of guano in the early part of the nineteenth century produced a decided change in the custom of agriculturalists in the use of locally produced manure. There was for the first time made available in concentrated form a fertilizing material which was reasonably inexpensive, convenient to handle and capable with ordinary care of being preserved for a long period of time and transported with little difficulty and expense.

The appearance of guano in the market was followed by the introduction of other manures possessing equally valuable properties. At the present time the home-made manures of the farm can, in the average case, compare but poorly with the purchased product. It has been well said that farmyard manure of average quality is of so little value that it is not worth while to pay the transportation charges upon it except for a few miles from its point of origin.

Had it not been for the introduction of guano and other concentrated fertilizers, it is doubtful whether the present methods of sewerage and disposal of city wastes would have found the common usage which they now enjoy. It would have been thought necessary to conserve the excrement of the human population of cities and towns instead of allowing it to go to waste, as has been prevalent in Northern Europe and America for the last sixty years. The fact that the excrement is removed by water and so little care taken to preserve it in form for agricultural use is in itself testimony that its value, as shown by the practical experience of agriculturalists, is not great.

The excrement of carniverous animals, of which man forms an example, is conceded to have greater manurial value than that of the domestic animals whose diet consists exclusively of vegetable matter, larger quantities of nitrogen being contained in it, yet is not so valuable as commonly supposed.

Factors Influencing the Value of Fertilizers

The conditions which determine the value of any fertilizer include not only the composition of the material but its stability on storage, its capacity for transportation, the convenience with which it can be employed and the competition in the way of price which it must meet from other fertilizers.

In regard to composition, it is necessary that the fertilizer shall contain certain chemical compounds which are required by the growing plants. Along with the needed ingredients there must be no harmful properties. It is not sufficient that there are the chemical elements needed for plant growth. They must be present in suitable form for ready assimilation by the crops. It is not sufficient that a fertilizer shall contain a requisite amount of nitrogen. Many of the compounds of nitrogen are of little or no use and must either be converted into assimilable substances in the soil or they are wasted, so far as the fertilizer is concerned.

One of the difficulties which must be overcome before human excrement can seriously compete with artificial fertilizers lies in the amount of water which fresh excrement contains. This water is in no wise useful. On the contrary, it adds to the bulk and weight of the material and favors decomposition changes which are likely either to lead to the production of offensive odors or the escape of much of the valuable nitrogenous content. It is with difficulty that the water can be expelled. It may be driven off by heat, but this is expensive and may result in the evaporation of some of the useful properties. The water can be withdrawn by means of absorbing agents, such as dry earth or chalk, but such desiccators are in themselves weighty and cannot readily be separated from the excrement. These remarks refer particularly to fecal matter. Urine, when considered from the standpoint of the quantity produced per capita per day, contains much more fertilizing material than fecal matter but is more difficult to deal with.

Stability on Storage. From what has been said under the last heading, it will be evident that there are serious difficulties in the way of storing excrement without impairing its manurial value and in any scheme of utilization, storage for considerable periods of time must play an important part.

The needs of vegetation require that fertilizer shall be applied only at certain seasons; during the rest of the time, it must be stored in a situation from which it can be transported to the fields without great cost, inconvenience or loss. Unless dried or preserved in hermetically-sealed containers, the loss by evaporation on storage may be considerable.

Transportation. No fertilizer can be profitably used unless the charges which have to be incurred for transporting it from its source to its destination are reasonable. The cost of transportation has probably operated more to prevent the utilization of excrement than any other one thing.

Various ingenious devices have been invented to transport excrement from its points of origin to its points of utilization. The dry conservancy system has had considerable popularity in England. The tinnettes of France and Belgium and the vacuum sewerage system of Liernur are the best practicable measures which have been employed for the transportation of excrement without water up to the present time.

No system has proved so effective as water carriage. As applied to cities, the advantages of water carriage are so obvious that municipalities are content to spend large sums to obtain the water which is necessary in order that modern sewerage systems can be employed.

The water carriage of excrement introduces a serious difficulty into the problem of utilizing human excrement. It is capable of facilitating the distribution of the fertilizing material upon land, but it adds immensely to the obstacles with which the useful ingredients may be extracted and concentrated in a form which is suitable for storage or long-distance transportation.

Convenience. It cannot be too strongly emphasized that convenience plays a leading part in determining the value of a fertilizer. It is convenience which requires that the fertilizer be of suitable composition and capable of storage and transportation. Convenience demands that the material which is used shall be in a form which can readily be distributed over the fields or in furrows, as the requirements of the crops demand. If too bulky and heavy, an excessive amount of labor will be required.

Competition with Artificial Fertilizers. In the last analysis the value of human excrement as a fertilizer will be found to depend upon the cost of other fertilizers which are capable of answering the same purpose.

Most Desirable Constituents of Fertilizers

The chemical analysis of plants shows of what they are composed and furnishes a key to the food which should be supplied to them.

The most important ingredient from the standpoint of weight is water, a fact which is of considerable interest from the standpoint of utilizing sewage. Crops such as are likely to be grown with the aid of excrement contain from 30 to 70 or even 80 per cent. of water, depending largely upon their physical constitution. Turnips and mangolds which are extensively grown on sewage farms in England contain so much water that the solid dry material in one ton scarcely weighs more than an average man.

The water of plants is almost exclusively derived from the soil. It is absorbed by the roots, a fact which should be kept in mind in sewage farming, since a frequent submergence of the leaves of some vegetables seriously injures them.

An essential element in the composition of vegetable matter is carbon. So universal is this element in the complex structure of living things that the science of organic chemistry has been described as the chemistry of the carbon compounds.

From the soil are obtained potash, lime, iron, silica and various other elements which are required in lesser degree. The important ingredient, nitrogen, upon the supply of which the vigor and abundance of growth so largely depends, is obtained by most plants from soluble compounds in the soil. In certain cases, as clover and other leguminous plants, nitrogen is absorbed from the atmosphere contained in the pores of the soil, certain forms of bacteria playing an important part in preparing the nitrogen for assimilation.

Function of the Soil. The soil serves two principal uses in agriculture. It affords a suitable standard of support in which the plants can establish a footing and it acts as a laboratory and reservoir for the preparation and storage of such chemical substances as the plants require for growth.

Practically all the food of plants can be assimilated only from dilute solutions. When fertilizers of any kind are applied to a field, they must first be dissolved by water before they can be appropriated by vegetation. Fertilizers differ largely in respect to solubility and this fact requires to be taken into consideration in determining at what season of the year the fertilizing material is to be employed. Farmyard manure which has to decompose and be resolved slowly into liquid form is usually applied in the autumn, whereas the ammonia and nitric acid compounds, if applied so long in advance of the requirements, are likely to leach away before they can be used. With sewage there is no choice as to the time of application. It must be employed when produced or not at all.

The Most Needed Compounds. The three most important ingredients of fertilizers are nitrogen, phosphoric acid and potash. In commercial fertilizers, the nitrogen is usually present in the form of ammonia or, as sold in the market, sulphate of ammonia. The nitric acid is most often sold in the form of nitrate of soda. Seventeen parts of ammonia or 66 parts of pure sulphate of ammonia contain 14 parts of nitrogen.

Phosphoric acid is derived from materials called phosphates, in which it may exist in combination with lime, iron or alumina. Phosphate of lime is the form most largely used. Phosphoric acid occurs in fertilizers in three forms: (1) That which is soluble in water and is readily taken up by plants; (2) that which is slightly soluble in water, but still readily assimilated by plants and is sometimes known as "reverted"; and (3) that which is very sparingly soluble in water and is consequently slowly used by plants. A fourth form, sometimes called odorless phosphate, is practically insoluble in water, but dissolves in the presence of certain salts or plant acids and, therefore, becomes useful as a ready source of phosphoric acid when applied to the soil. This and the soluble and reverted types are known as available phosphoric acid.

Organic phosphates are contained in bone, which is now the only one of the so-called insoluble phosphates that is not largely used without other change, and it is prepared by mechanical action such as grinding. Other phosphates from bone, such as bone-black, bone ash, etc., are little used.

The term tankage is applied to the dried and ground animal wastes of abattoirs and packing establishments. The material is thus designated because it is the residual product after the waste portions of the carcass are steamed under pressure in large tanks for the extraction of the fatty substances.

The mineral phosphates differ from so-called organic phosphates in that they contain no organic or animal matter and are more compact. They are extensively derived from river and land phosphate beds in South Carolina, Florida and Tennessee and phosphatic slag which is a waste product from the manufacture of steel, from certain iron ores. All except the slag are treated with acid before use.

Super-phosphates or soluble phosphates are derived from the insoluble materials by grinding them to a powder and mixing them with sulphuric acid. The term superphosphate is applied to any material containing soluble phosphoric acid as its chief constituent.

Potash exists chiefly as chlorides or muriates and as sulphates. The form does not exert so great an influence upon the availability of the potash as in the case of nitrogen and phosphoric acid. All forms used in the fertilizer industry are freely soluble in water and are believed to be nearly, if not quite equally, available as plant food.

The chief sources of potash salts are the potash mines of North Germany. Kainit and sylvinit are crude products of the mines. The mine products may be used in crude condition, or, after chemical treatment, in the form of various salts.

Potash salts are used to best advantage on light, sandy humus and calcareous soils.

Standard materials in the fertilizer industry are those which do not show a wide variation in composition and in which the constituents are practically uniform in action. Nitrate of soda, sulphate of ammonia, dried blood and super-phosphates and potash salts are all standard products, as they can be depended upon both as to product and the form of their constituents. Ground bone, on the other hand, is non-standard, because it is variable in composition and in the availability of its nitrogen and phosphoric acid.

The agricultural value of a plant food is not a fixed quantity. It varies according to the availability of the constituents, as well as upon the value of the crop. It should be based upon the crop increase which its use produces.

The agricultural value should not be confused with the commercial value or cost of the fertilizer in the market. The latter is determined by market and trade conditions, as the cost of the crude materials and the methods of their subsequent treatment. The commercial value does not necessarily bear a direct relation to the agricultural value.

The computation of the commercial value of complete fertilizers is illustrated in the following table.

TABLE LII

Methods of Computing Values of Complete Fertilizers

Constituent	Pounds per Hundred	Pounds per Ton	Value per Pound of Constituent	Value of Constituent per Ton of Fertilizer
Nitrogen:			Cents	
As nitrate	1	20	17.0	$3.40
As ammonia salts	1	20	17.5	3.50
As organic matter	1	20	18.5	3.70
Phosphoric acid:				
Soluble	8	160	4.5	7.20
Reverted	1	20	4.5	.90
Insoluble	1	20	2.0	.40
Potash:				
Muriate	5	100	4.25	4.25
Sulphate	5	100	5.0	5.00
Total value per ton				$28.35

The first figure column shows the per cent. (pounds per hundred) of the constituents contained in the fertilizer; the per cent. multiplied by 20 gives the pounds per ton in the second column; the figures in the latter, multiplied by the schedule prices per pound in the third column, give the valuation per ton, as shown in the fourth column.

The direct value of a fertilizer is determined by the percentage of nitrogen, phosphoric acid or potash which it contains, hence the buying of a fertilizer is virtually the buying of one or more of these constituents. The more concentrated the material, the less will be the proportionate expense of handling it. As a rule, farmers are inclined to purchase fertilizers on the ton basis without regard to the amount or form of the constituents contained in them.

High grade mixtures cannot be made from low grade materials. The following table illustrates the methods by which brands of fertilizers may be made up.

TABLE LIII

Formula for Making Fertilizer

	Pounds		Pounds		Per Cent.
Nitrate of soda	500,	furnishing nitrogen	80,	or	4
Boneblack super-phosphate	1,100,	furnishing phosphoric acid	180,	or	9
Muriate of potash	400,	furnishing potash	200,	or	10
Total	2,000,	furnishing total plant food	460		

This formula shows a high grade product both as to quality of plant food and concentration.

The charges of manufacturers and dealers for mixing, bagging, shipping and other expenses are said to be on an average about $7 per ton, and the average actual fertilizing constituents per ton are said to weigh about 300 pounds.

The foregoing remarks upon commercial fertilizing materials are based upon Farmers' Bulletin No. 44, by Edward B. Voorhees, U. S. Department of Agriculture.

The Composition of Human Excrement

The composition of excrement as collected by city scavengers depends greatly upon the methods of collection, the presence or absence of other materials and the circumstances under which the excrement has been kept until the time of collection. Leaching and fermentation are capable of materially changing the fertilizing value of the mass.

Analyses of Feces and Urine. In a general way it may be said that solid human excreta as they leave the body contain about one-fourth of their weight of dry matter and three-fourths water. The dry matter contains about 1½ per cent. of nitrogen and 1 per cent. of phosphoric acid.

According to Professor Way, formerly consulting chemist of the Royal Agricultural Society of England, human feces contain the ingredients shown in Table LIV.

TABLE LIV

Composition of Human Feces

	In Fresh Condition	If Dried Without Loss of Fertilizing Properties
Water	75.00%	.....%
Organic	22.13	88.52
Insoluble silicious matter	.37	1.48
Oxide of iron	.13	.54
Lime	.43	1.72
Magnesia	.38	1.55
Phosphoric acid	1.07	4.27
Sulphuric acid	.06	.24
Potash	.30	1.19
Soda	.08	.31
Chloride of soda	.05	.18
	100%	100%
	Containing nitrogen 1.50 equivalent to ammonia 1.82	Containing nitrogen 6.00 equivalent to ammonia 7.28

If perfectly dry, 2 tons of solid human excreta are worth about as much as 1 ton of Peruvian guano. The urine is more valuable on account of its urea. Urine contains nearly 50 per cent. of nitrogen and a considerable amount of phosphoric acid.

According to Professor Way, the solid ingredients of urine are as shown in Table LV.

TABLE LV

Composition of Human Urine

Organic matter	67.54%
Insoluble material	.09
Oxide of iron	.05
Lime	.61
Magnesia	.47
Phosphoric acid	4.66
Sulphuric acid	.46
Potash	1.83
Chloride of potash	5.41
Chloride of sodium	18.88
	100%
	Containing nitrogen 19.43 equivalent to ammonia 23.60

Notwithstanding the large proportion of water, the solid matter voided in urine in a day is just about one-third greater than the amount of dry matter in the daily solid evacuations. Five-sixths of the ammonia which is capable of being generated by the decomposition of human excreta is furnished by the urine.

Professor Way found that one adult voids in 24 hours about one-fourth of a pound of feces and 3 pounds of urine. Hence, in 4 ounces of feces there is 1 ounce of dry matter or nearly 23 pounds per annum. In 3 pounds of urine there is 1½ ounce of dry matter or nearly 34 pounds per annum. The ammonia from the 23 pounds of feces amounts to 1.60 pound and from the 34 pounds of urine 8.12 pounds, or a total amount of 9.72 pounds of ammonia per year.

Each adult furnishes about 5½ pounds of phosphates per year. Briefly, 56 pounds of dry matter is produced per year, containing 10 pounds of ammonia and 5½ pounds of phosphoric acid. Allowing 16 cents per pound for the ammonia and 5 cents per pound for the phosphates and 1 cent per pound for the remaining constituents, gives a total value for the excreta per capita per year of $2.27.

PRACTICAL ATTEMPTS TO UTILIZE SEWAGE

In China, Japan, Belgium, France, Italy and Spain, and in some parts of England there appears to be little or no objection caused by storing, transporting and manipulating human excrement, but in America the case is different. These practices are felt to destroy the self-respect of those persons who are engaged in them. Those whose business it is to clean privies and cesspools are generally regarded with aversion. They often carry on their work at night and not infrequently with an appearance of secrecy. Nominally under the jurisdiction of boards of health, the business of privy cleaning is too often conducted with little more regard for honesty and efficiency than the shrewd judgment of the scavengers and the absence of oversight deems necessary. The work is done with little or no regulation as to expense and seldom, if ever, until absolutely required.

Such manurial value as the contents of the privies and cesspools possess is usually lost in America, the custom being for the scavengers to dump the material into some convenient out-of-the-way spot without any other idea than to get rid of it.

It is probable that the contents of American privies are usually of inferior worth, since most of the valuable liquid material leaches away in the vault and there is customarily a considerable amount of ashes and other refuse intermixed with the useful matters. Furthermore, owing to the infrequency with which the receptacles are cleaned, fermentation has usually occurred with the result that much of the more useful manurial property has been converted into ammonia and nitrogen gas and lost into the atmosphere.

According to European experience, night soil is a relatively concentrated manure and is generally applied to the land in diluted form. It is often mixed with other kinds of manure and so serves to reinforce the nitrogen of the latter or, it may be diluted with from two to six times its bulk of water and so applied. Sometimes it is dried and applied as powder, as was once done in Paris and other cities. Occasionally it is mixed with assorted refuse collected from the streets and houses and composted, as in Holland.

Before the general employment of water to carry away the excrement of cities, many attempts were made to chemically treat night soil, either collected in combined condition or the feces and urine separately, in order to recover the useful fertilizing ingredients, and various processes of evaporation were employed to get rid of the liquid matters and recover the solids in relatively concentrated condition. Among these processes is that known as Taffoe. This was prepared by kneading excrement and loam together, moulding the mass into bricks and drying the latter in air.

Another process mixed excrement with magnesium sulphate and sulphate of iron with a little tar and potash and evaporated the clarified liquid by permitting it to trickle over fagots held upon a frame, as is done at some places to recover salt from brine. The solid matters which collected upon the fagots were broken up and sold.

One inventor proposed to treat fresh excrement with smoke in order to prevent it from putrefying, then dry it partly with artificial aid and partly with absorbents and finally mould the material into bricks which would be dried in air and finally crushed to powder.

A compound known as urate was prepared in England by adding gypsum to urine and drying the precipitate produced.

Sulphate of urine was made by adding enough sulphuric acid to stale urine to neutralize the ammonia and then evaporating the liquid to dryness.

Bolton and Wanklyn proposed to drive off the ammonia from urine by heat and absorb it by means of sulphate of lime, thus producing sulphate of ammonia. It was once believed by chemists that both ammonia and phosphoric acid might be precipitated from urine by means of a magnesium salt and experiments were made to this end.

Many processes have been employed for the treatment of excrement by lime, chiefly as a preservative until the material could be transported to fields where it was to be employed.

One of the most successful chemical processes for the treatment of night soil is the preparation of sulphate of ammonia, as practiced in Amsterdam. The principle is to add lime to the excrement and by this means and through heat drive off the ammonia which is subsequently absorbed by sulphuric acid with the ultimate production of a clean, white, inoffensive salt, sulphate of ammonia.

Among the best known fertilizers produced from sewage in England during the period when the manurial value of sewage was considered most worthy of being conserved was the product called native guano produced by the A B C process. A description of this process is illustrative of many.

The A B C process received skilful and adequate attention from the consulting chemist of the Royal Agricultural Society of England at a time when the product was widely advertised and offered for sale at $25 per ton at any railway station in England or Wales. The report of the chemist, A. Voelcker, F.R.S., was published in the journal of the society, Volume VI, 2nd Series, page 415.

The claim of the company was that it could extract a valuable, dry, artificial manure from liquid sewage and render the sewage as clear as water and sufficiently pure to be discharged into a river or water course without causing any nuisance. The principle was to add a precipitating reagent to the sewage and dry the resulting deposits. The reagents consisted of alum, blood, clay, magnesia, manganate of potash, burnt clay, chloride of sodium, animal charcoal, vegetable charcoal and magnesium limestone. The proportions in which these ingredients were to be added varied according to the particular sewage to be treated. The resulting deposit was dried in centrifugal machines which caused a reduction of about 50 per cent. of the contained water. The material was then spread out in thin layers to the sun and on becoming sufficiently dry was bagged and sent out.

Because of his official position as chemist to the Agricultural Society, Voelcker received a number of samples of native guano, as the A B C product was called. He found that about seven-eighths of the useful fertilizing value of the sewage escaped in the dissolved matter and one-eighth only remained in the solids in suspension. The worth of the product was greatly exaggerated. The value varied widely. The minimum for the samples sent to him was about $3.62 and the maximum $8.11 per ton. To use Voelcker's language: "At these prices all the really valuable fertilizing constituents in a ton of this manure may be purchased in a concentrated form and be easily carried by a lad on the field in a very small bag." He considered it better to compare the material with ordinary farmyard manure than to regard it as a compound of high fertilizing value. Four of the samples of native guano examined were practically worthless if carted 10 miles from the place where they were manufactured.

Poudrette. The process of drying night soil in order that it may be transported and used for fertilizer was at one time carried on in a suburb of Paris on a large scale and in New York and many other cities. The product was known as poudrette. At Paris some old quarries supplied the site where the material was prepared. A number of the excavations were used as settling basins, the liquid portion running off and the solid matters remaining behind. When a large accumulation of solids had collected, they were removed to nearby fields and spread out upon the land to dry, the process of drying being facilitated by occasional harrowing.

The final result was a dry, inoffensive powder which seems not really to have had great fertilizing value, but was so convenient to use and appeared to contain so much of value that the production of poudrette became an extensive undertaking.

It would appear that changes took place in the settling basins which were more than mere sedimentation and less than complete septicization. The odors produced are said to have been exceptionally offensive, from which it may be inferred that fermentation was the predominant microbic action and from which it would appear that much of the nitrogen was escaping to the atmosphere in the form of ammonia.

The following analysis of the poudrette produced at Montfaucon, a suburb of Paris, as well as at works at New York, Hartford, Dresden and Cologne, show the approximate value of the product. The ingredients varied considerably at different times and among the works in the different cities.

TABLE LVI

Composition of Poudrette from Various Sources

	Water	Organic Matter	Total Nitrogen	Ammonia	Nitric Acid	Phosphoric Acid	Lime
Montfaucon:							
Boussingault and Payen	1.41		1.56				
Jaquemont			1.90				
Soubeiran (1847)	28–32	29.00	1.78	0.73		3.73	
L'Hote (1848)	30.20	32.81	1.52	0.59	0.30	4.18	6.70
N. Y. City, Lodi Mfg. Co. (reported by S. W. Johnson)	32.52	14.88	0.95			1.06	1.05
	15.60	18.40	0.98				
	25.62	14.80	0.95				
Hartford, Conn. (S. W. Johnson)	39.97	20.57	1.01			0.87	
Dresden:							
(Müller)	19.50	20.80	2.10			2.50	2.70
(Scheven)	18.42	11.25	1.34				
(Bretschneider)	15.91	35.12	1.68			2.75	
Cologne (Grouven)	12.80	36.20	2.01			3.01	

Compost. By composting is meant the systematic mixing together of various fermentable waste substances in a heap and permitting a sufficient interval of time to pass for the fermentation of the mass. Composting is a common practice in German and Dutch cities and in view of the value of the product obtained, the ease of preparation and the completeness with which all necessary sanitary requirements are complied with, it is surprising that more use has not been made of this principle elsewhere.

It is true that composting is widely practiced in America, but it is employed for another purpose. Farmyard manure which is allowed to rot is composted. But the method which is generally employed in the United States is wasteful in the extreme and is usually carried on with a poor idea of the underlying principles upon which the best results may be procured.

The city composts which are prepared on the continent of Europe are generally mixtures of street sweepings, garbage and other refuse with some excrement and enough moisture to insure satisfactory fermentation. In the central depot for the disposal of the city wastes of Amsterdam, the compost heaps are arranged in an orderly manner, provided with suitable drainage and built up and removed with a degree of skill which is the result of long experience.

UTILIZATION THROUGH FARMING

The English, who were among the first to apply sewage to land, first with the object of disposing of the sewage and second with the intention of gaining a profit from the utilization of the manurial ingredients, divided the methods of application into three classes according to (a) the presence or (b) the absence of underdrainage and (c) combination with chemical or other preliminary treatment.

The oldest method, called broad irrigation, does not employ underdrainage. Its efficiency depends upon the purifying action which takes place near the surface of the soil. In preparing the land, shallow ditches are dug approximately following the contours of the ground and tending toward slightly lower places where that part of the sewage which does not soak into the soil at first may be collected.

Irrigation was practiced in Europe prior to the year 1400, but the earliest use of sewage in this way was at Bunzau, Prussia, in 1559, where about 35 acres of privately owned land were irrigated for over 300 years. The Craigentinny Meadows, near Edinburg, have received sewage for some 200 years. Between 1860 and 1880 the development of sewage farming in England was rapid. On the continent, Paris adopted this method in 1865, Dantzic in 1869 and Berlin in 1876. By 1883 there were over 200 sewage farms in Great Britain.

In 1868 a Royal Commission announced that: "Irrigation is the only process of cleansing sewage which has stood the test of experience." But from that time it was gradually displaced by chemical precipitation processes.

In the United States there were, in 1910, about 103 small plants employing sand filtration, a few of which cultivated crops incidentally. Many of these were in Massachusetts, where cropping is becoming less frequent. Aside from these, there were in the year mentioned the following towns employing broad irrigation:

Arizona	Tucson
California	Fresno
	Hanford
	Pleasanton
	Riverside
	Imperial
Kansas	Hiawatha
	Holton
	Humbolt
Massachusetts	Leicester
	Lenox
Massachusetts	North Brookfield
	Stockbridge
Michigan	Caro
	St. Johns
Montana	Red Lodge
	Helena
New Jersey	Pemberton
	Princeton
Ohio	Fostoria
Pennsylvania	Altoona

Proper Soils for Sewage

A great deal of discussion has taken place during the last fifty years concerning sewage farming, especially with respect to certain details. The result has been to show that no rules can safely be laid down which are strictly applicable to all soils and all situations.

Soils differ in their capacity for absorbing sewage according to their physical and chemical composition as well as to the biological processes which they can readily support.

Before estimating closely upon the capacity of farm land for sewage, it is desirable that mechanical, chemical and biological analyses of it should be made.

The composition of the soils of sewage farms may be materially altered by the improper application of sewage. Crude sewage is capable of depositing a layer of black, decomposing material upon the surface which clogs the openings between the soil particles and prevents further absorption of sewage and of the oxygen necessary for nitrification. Land thus heavily coated with sewage deposits often produces serious nuisance from odor and if the application of sewage is continued, the soil becomes useless. Land in this condition is said to be "sewage sick." Where large quantities of sewage are being applied to land, it is usually necessary to open up the soil by plowing. On some sewage farms a large amount of hand labor is required.

The best soil for a sewage farm is of light, porous consistency overlying gravel. The level of the ground water should be rather low; low enough to permit the fields to be well underdrained. There should be water courses nearby of sufficient size to carry off, without harmful consequences, such excess of sewage as it may from time to time be necessary temporarily to discharge without thorough purification. The land should be inexpensive and of great enough extent to permit the sewage to be applied without excessive dosing. It is an advantage when the farms are remote from villages and other thickly inhabited areas. There should be a ready market for the produce yielded by the farm.

Unfortunately, the land within easy reach of great cities is usually divided into relatively small plots and held by many owners. It is rather costly and any odors produced upon it are likely to cause a nuisance to many persons. Every great city is, in fact, surrounded by villages and towns and the opportunities for sewage disposal by application to farm land are likely to be in reverse proportion to their need. It is usually necessary to go a long distance from the center of a large city to find a district which is sufficiently rural to possess ideal conditions for sewage disposal.

Capacity of Farm Land

The quantity of sewage which can be applied to farm land depends upon so many factors that no exact rule can be applied to it.

Table LVII, taken from the Fifth Report of the Royal Commission on Sewage Disposal, gives in concise form the quantity of sewage which may properly be applied to one acre of land.

TABLE LVII

Quantity of Sewage Which May Be Applied to Land

Conditions	Imperial Gallons Settled Sewage per Acre Daily	Acres per Million Imperial Gallons Dry Weather Flow
Good soil and subsoil:		
Filtration with cropping	12,000	84
Filtration with little cropping	25,000	40
Surface irrigation with cropping	7,000	145
Heavy soil overlying clay:		
Surface irrigation with cropping	5,000	200
Stiff clayey soil overlying dense clay:		
Surface irrigation with cropping	3,000	334

Moore and Silcock in their work on Sanitary Engineering (1909) give the approximate volumes and populations that can be taken care of by an acre of different soils and with crude and settled sewage, as shown in Table LVIII.

TABLE LVIII

Allowance of Land for Sewage Treatment

	Crude Sewage		Settled Sewage	
	Imperial Gallons	Population	Imperial Gallons	Population
Light sandy loam on gravel and sand	15,000	375	20,000	500
Sandy loam on gravel and sand	12,000	300	17,000	400
Peaty soil on gravel and sand	10,000	250	13,500	325
Sand and gravel	8,000	200	10,000	250
Gravelly loam on gravel and sand	6,000	150	8,000	200
Loam getting more clayey	4,500	125	6,000	150
Heavy loam on marl	3,000	75	5,000	130
Clay soil on clay	1,500	50	4,000	120
Stiff clay soil on dense clay	1,000	33	3,000	100

The figures in the foregoing table are based on an assumed daily flow of 40 imperial gallons per capita.

Rideal estimates that the sewage from 100 persons can be treated on an acre of loamy gravel and that the number may rise to 500 under rarely favorable circumstances, while with stiff clay it falls to 25. The rates commonly used in England vary from 2,000 Imperial gallons per acre per day at Leamington and Wrexham to 15,000 gallons at Cheltenham. In Germany, "with, on the whole, better preparatory treatment and a more favorable soil, the rates in general use range from 2,000 gallons per acre per day at Brunswick to 7,000 at Danzig, and probably average about 4,000."

In the opinion of the Royal Commission on Sewage Disposal, quoted by Scoble in his book on Land Treatment of Sewage, the maximum limits of the rate of application to land by irrigation are as shown in Table LIX.

TABLE LIX

DATA RELATING TO ENGLISH SEWAGE FARMS

Name of Farm	Nature of Sewage	Nature of Soil and Subsoil	Method of Treatment	Acres of Land Under Treatment	Imp. Gals. per Acre Daily of Land Under Treatment	Population per Acre of Land Under Treatment	Observations (Condensed)
Aldershot Camp.	Domestic.....	Sand............	Screening, settling, land filtration...	120½	8,300	166	Strong sewage, effluent fair.
Altrincham.....	Domestic.....	Peaty soil on sand and gravel......	Settling, land filtration............	35	23,000	514	Effluent would be good with somewhat less volume.
Cambridge......	Mainly domestic.........	Sandy loam on gravel and sand..	Screening, settling, land filtration...	74	30,400	675	Effluents good but not in highest class.
Croyden (Beddington)......	Domestic.....	Gravelly loam over gravel and sand..	Screening, part surface irrigation filtration.........	420	9,500	238	9,500 gals. per acre somewhat too high.
Leicester........	¾ domestic, ¼ trade refuse.	Stiff clayey soil over dense clay......	Screening, settling, surface irrigation and filtration....	1,350	5,370	146	Too large volume for best results.
South Norwood.	Domestic.....	Clay soil on London clay........	Screening, settling, surface irrigation	152	4,000	138	Too large volume for best results.
Nottingham.....	⁴⁄₇ domestic, ³⁄₇ trade refuse.	Light, sandy loam and gravel on gravel and sand..	Screening, land filtration.........	651	10,750	397	Effluent uniformly of high quality.
Rugby..........	Mainly domestic.........	Heavy loam over stiff clay........	Screening — chemical precipitation, settling, surface irrigation and filtration.........	35	8,500	171	Volume too great for highest class effluent.

The quantity of sewage which can be applied to crops during rainy weather is very small and the difficulty which arises from this fact is increased because the volume of sewage is itself augmented by the rain. If, as commonly occurs, there is no more land than is needed for the ordinary flow of sewage, it becomes necessary in stormy weather to discharge the sewage from the farm in an incompletely purified condition or treat it by some supplementary process.

In America, comparatively little can be done in sewage farming and that which has been accomplished has been under conditions which are not general. The sewage farms have all been small. Consequently, there is little useful data available from this country. On the Passadena farm, with 300 acres under irrigation, the volume disposed of per acre daily was about 2,800 gallons. On the intermittent filtration area at Framingham, Mass., crops were formerly grown with a rate of about 40,000 gallons per acre per day. This was with comparatively weak, screened sewage.

Method of Applying the Sewage to the Land

The methods of applying sewage to the land vary considerably. The simplest plan is to allow the sewage to flow over the surface, the sewage being conducted to the fields by ditches and the effluent being carried away by open drains. The farms are usually so arranged that where passage across one field fails to purify the sewage sufficiently, the sewage can be conducted over other fields located at lower levels. This kind of sewage irrigation is most suited to clayey and peaty soils which do not readily permit the sewage to pass through. Some authorities consider that soils of this kind are not suitable for sewage farming and should not be used for this purpose. In Germany, it is customary to make careful study of the soil which is available before deciding upon a sewage farm and only in those cases where soil of proper character can be obtained is it considered permissible to lay out a sewage farm. In England the custom of restricting sewage farms to those soils which are suitable has not always been followed, and farms have often been laid out on very unsuitable soil. In some cases it was impossible to find proper soils and the insistence of the Government upon the application of sewage to land made it necessary to use such soils as were available.

The purification effected by allowing sewage to flow over the surface of the land is relatively slight and uncertain. This is the crudest method of applying sewage to farm land. Where suitable soil exists, it is desirable to construct underdrains so that the sewage can pass through the soil and so undergo the purification which can best be carried on in the ground. The underdrains are arranged in various ways according to local circumstances and the personal opinions of those who happen to be in charge of the work; no exact rules being followed. The underdrains may lie from 3 to 6 feet beneath the surface and they may be from 30 to 50 feet apart. Their slope is generally about 1 in 200.

Ridges and Furrows. The sewage is conveyed to the field in open ditches and may be spread over the soil evenly or in furrows. Where furrows are employed, it is customary to dig them between the lines of underdrains so that the sewage may pass as far as practicable through the soil. The crops are sown on the ridges between the furrows.

The ridge and furrow system has many advantages. Among them is the opportunity afforded for applying the sewage to the roots without fear of doing harm by wetting the leaves and upper stems.

The sewage is always applied intermittently. The frequency and duration of dosing varies considerably. The sewage may be run upon the land for a period of 24 hours at intervals of every four or five days or it may be applied during a longer period with a shorter interval of rest. As a general rule, it is customary to allow from 2 to 4 times as long a period between applications as is allowed for the application itself.

Preliminary Treatment. It not infrequently occurs that sewage has to be treated by some process before it is applied to land. If the large solids are not removed, the land may become not only covered with black, slimy deposit, but worse, a fetid mat of solids may accumulate in the pores and on the surface of the soil which greatly retards the penetration of the liquid sewage.

In some cases it is desirable to remove the grease from the sewage before applying it to the land. The total quantity of grease produced in some cities where manufacturing processes are carried on is very great. Studies made at Berlin indicate, according to Dunbar, that about 20 grams of grease are produced per capita per day. This is sufficient to spread one-half a gram of grease over each square yard of the land at the sewage farms per annum. Grease is of no use whatever in agriculture; it is harmful to the sewage farm.

If sewage has to be treated for the removal of its solid matters and grease before the sewage is applied to the land, the cost of sewage farming is increased.

THE INTERESTS OF SANITATION AND OF AGRICULTURE OPPOSED

The interests of sanitation and of agriculture are frequently opposed in sewage farming. It is of sanitary advantage to apply the sewage in such way as will produce the highest degree of purification and this must be done regularly and with little or no odor or other nuisance. The sewage must be disposed of promptly and at the rate at which it is produced. It should not require expensive preliminary treatment in order to fit it for absorption by the soil. The state of the weather should produce no injurious effect upon the process of disposition. The increase in volume produced by the growth of population should not require expensive additions to the works. There should be no danger of injury to health. Extensive harm to property in the vicinity of the works should not result. The interests of agriculture require that the sewage be applied only when needed and in such quantity only as to satisfy the needs of the growing plants. In winter and in heavy storms no sewage is wanted.

FACTORS AFFECTING RESULTS OBTAINED BY SEWAGE IRRIGATION

Climate. Climate is an important factor in determining the suitability of sewage farming. Where the atmosphere is humid or the rainfall abundant, less sewage can be taken up by vegetation than in the arid regions. With heavy downpours, special provision is required in the way of equalizing basins or filters. Arid regions, such as those of India, Egypt and our own West are particularly favorable for the reception of sewage for irrigation. Cold climates, on the contrary, are not so suitable. When led onto the fields in furrows, sewage does not freeze except during very low temperatures provided the supply of sewage is nearly continuous, but it is, of course, not usefully employed under these conditions.

Sanitary Considerations. Although slight odors may be carried for some distance during certain atmospheric conditions, there is no evidence that sewage farms are detrimental to health. This is the experience on the farms of Berlin on which over 4,000 persons reside on 39,000 acres, and is the conclusion reached by the Royal Commission on Sewage Disposal.

Crops to be eaten raw should not be dosed with sewage before gathering and, in fact, the experts of the Royal Commission on Sewage Disposal, Messrs. McGowan, Houston and Kershaw, would even go so far as to limit sewage farms to the raising of food for cattle, but this seems an unnecessary restriction. Waring, in his "Modern Methods of Sewage Disposal," says that "after all these years of experience, it may be stated in the most positive manner that there is no sanitary objection whatever to the system of sewage disposal by agricultural irrigation."

There remains to consider the possible pollution of water supplies. If the land is underlaid by limestone, chalk or seamy rock or beds of coarse gravel from which supplies are taken, there is danger of contamination; but if the soil is fine and homogeneous, the effluent may be able to satisfy the standards of a drinking water on a well operated farm.

The location of the farm with reference to the city is important, first, in its effect on the price of land, and consequently the cost of the farm, and second, in its proximity to a market for the products. The distance of the farm from the city affects the character of the sewage, for sewage becomes offensive with long carriage.

Sociological Conditions. Sociological conditions are so different in Europe and America that it is unsafe to infer from foreign experience what might be accomplished in the United States in this respect. If the farm and the condition of the effluent are to be entirely under the control of the municipality, a large body of employes must be added to those already on the city's pay-roll. Where the control is by an intelligent and strong centralized government, as in Germany, there is relatively little objection from this standpoint.

Greater efficiency in operation might be secured by a private corporation than by a city, but the principle of relegating the function of purifying sewage and operating a productive farm to any but a public authority is not wise, as the profits to be derived from the sale of crops would be pushed, to the probable neglect of the sanitary considerations.

CROPS

With the exception of cereals and legumes the crops best adapted to sewage farming are those which it is found most profitable to raise on other farms in the neighborhood, provided they have a large capacity for taking up water. Italian rye grass has been found one of the best crops to raise, and cabbages, kale, mangolds, beets, turnips, carrots, onions, potatoes and celery thrive well. In England, osiers have been found to grow well in wet irrigated soils and at Sutton the raising of mint for oil was found profitable. Cabbage is said to be injured in flavor by sewage and it should not be applied to lettuce, berries or other farm products which are to be eaten raw.

It is often profitable to devote a part of the land to pasturage. In this way the crops are, at least in part, disposed of without cost for transportation and, if produced in excess, can be stored by ensilage for future use. Cows and horses are an important source of revenue on the Reading, Nottingham, Aldershot and other farms in England and the sale of wool from sheep constitutes a principal source of revenue on the Melbourne farm. Where cows are raised, milk is a valuable product. The proper management of a large sewage farm therefore requires in the manager a man of unusual qualifications pertaining to irrigation, farming, stock raising and the dairy business.

NUISANCES FROM ODORS

Sewage farms not infrequently give rise to considerable nuisance from odors. This is particularly true where the extent of land is insufficient to take care of all the sewage which needs to be disposed of. At best the exposure of sewage through several miles of open ditches is not an agreeable procedure when regarded from the aesthetic standpoint. It is true that in some cases, notably at the sewage farms of Berlin, hospitals, convalescent homes and even playgrounds for children have been arranged at no great distance from the sewage fields; but in those cases where high sanitary standards exist, the advantages to agriculture are considered of distinctly secondary importance and the success of the process, as reckoned from the business standpoint, is generally poor.

The secret of successful application of sewage to the growing of crops lies in having a good soil to work with, providing scientific management and in having an abundant area of land. The crops should be given sewage only when they want it. Saturation of the soil, known as sewage sickness, should never occur. There should always be reserve areas to take up the excess volume which frequently occurs. The land in the vicinity should not be of such great value as to prevent extensions being made to the works which the increasing quantities of sewage from growing populations require. Nor should the works be situated so close to villages and towns as to cause the latter to suffer seriously from the odors to which the sewage fields may give rise.

It should not be necessary to produce an effluent of the highest chemical and bacterial purity. Sewage farming is capable of producing an effluent which is as clear and clean as any process of sewage treatment can yield, but this result can be achieved only under favorable circumstances. It has frequently been remarked by impartial experts that in very few places are rigid sanitary requirements fulfilled by sewage farms. In numerous instances, it has been necessary to abandon farms in order to obtain a disposition of the sewage which would be satisfactory from the sanitary standpoint.

EXAMPLES OF SEWAGE FARMS

PARIS

TABLE LX

DATA RELATING TO THE SEWAGE FARMS

Population, 1910	2,800,000
Population, per acre	221
Ordinary volume of sewage per day	160 to 185 million gallons
Ordinary sewage per head per day	57.1 to 64.8 gallons

Farm	Areas of Farms in Acres		Total
	Privately Owned	Owned by Municipality	
Gennevilliers	1,996	15	2,011
Acheres	386	2,965	3,351
Mery-Pierrelaye	3,731	1,235	4,966
Carrieres-Triel	2,137	210	2,347
	8,250	4,425	12,675

The soil is largely a sandy alluvial deposit with some gravel and some clay down to a depth of from 6 to 20 feet. It is partially underdrained at 13 feet. The sewage before delivery to the farms has passed through a grit chamber and screen.

From Table LX the average amount of sewage applied per acre per day is seen to be about 13,600 gallons, although the volume received at Gennevilliers is restricted by law to 11,800 gallons per acre daily. Experiments have shown that in raising lucerne the land will take 42,700 gallons and that meadow land will take 49,300 gallons per acre daily without prejudice to the crops or effluent. At Gennevilliers there is a "model garden" where various fruits, flowers, vegetables and shrubs are grown and it has been shown that this will take from 23,000 to 37,000 gallons per acre per day.

On the lands owned by the city, sewage is taken by the tenant in fixed amounts and its use is under the supervision of the city but in the larger area privately owned, it is taken or rejected at the option of the farmer. There is much that finds its way to the Seine without treatment during storms. The sewage used in irrigation is discharged to the river in a well purified condition.

The cost of the farms up to 1900 was $7,220,000 and the annual operating expenses were about one million dollars. The Gennevilliers crop was worth about $200 an acre or $400,000 in 1907. Data for the other farms are lacking.

It is a significant fact that the city has been carrying on experiments with more intensive methods of sewage treatment for some years.

BERLIN

TABLE LXI

Data Relating to the Sewage Farms

Population in 1910	2,064,153
Sewage treated per day	77 million gallons
Sewage, per capita, daily	37 gallons

	Area of Farms in Acres			Total
	Farmed by City	Leased to Market Gardeners	Unproductive	
Acreage irrigated and farmed	16,657	3,956	395	21,008
Acreage farmed without irrigation	10,647	2,486	8,868	22,001
Total	27,304	6,442	9,263	43,009

At the end of 1910 there were the areas of prepared land as shown in Table LXII.

TABLE LXII

Areas of Prepared Land

Used for broad irrigation	7,994 acres
Used for filtration bed	12,250 "
Used for settling basins	502 "
Roads and miscellaneous	2,105 "
Total	22,851 "

The soil is light and sandy. The beds are about 150 to 200 feet square and are underdrained at a depth of from 4 to 6 feet by lines of tile 16 to 30 feet apart. The grit and heavier sludge and fats are removed before applying the sewage to the land.

The rate of filtration is about 3,700 gallons per acre of prepared land. There are 48 inhabitants per acre of farm or about 98 per acre of land under irrigation.

The principal crops raised are rye grass, turnips, beets, cabbages, potatoes and grain. About a quarter of the area operated by the city is pasturage. There are 40 acres of fish ponds which yield about $80 worth of fish, mostly carp, per acre per year.

The total cost of the farms to March 31, 1910, was $17,470,000. The cost per acre was as shown in Table LXIII.

TABLE LXIII

Cost of the Sewage Farms

	Total Area	Land Specially Prepared
Purchase of land	$229.38	$431.52
Preparation of land	131.40	247.80
Buildings and miscellaneous	45.42	85.26
Total expenses	$406.20	$764.58

The receipts and expenses of operation in 1910 were as shown in Table LXIV.

TABLE LXIV

Running Expenses of the Sewage Farms

Receipts	$1,240,772.58	
Increase in value of live and dead stock	122,593.50	
		$1,363,366.08
Maintenance	$1,300,385.34	
Payment of interest and loans	741,817.62	
		741,817.62
Deficit		$678,737.88

From the foregoing figures there is seen to be a decided loss when the fixed charges on capital invested are included.

The Berlin farms are the most extensive and perhaps the best managed in the world. They are under the control of the authorities, are on land admirably adapted to the purpose, convenient to the markets and employing in part convict labor at low cost. Yet, largely on account of the increasing value of the land, it is Dr. Dunbar's opinion "that many of us will live to see the day when Berlin will sell its irrigation farms for building purposes and construct artificial biological works in their place."

NOTTINGHAM

TABLE LXV

Data Relating to the Sewage Farm

Population drained to sewers in 1910	258,584
Population per acre irrigated	397
Mean dry weather flow	8,400,000 gallons per day
Sewage per head per day	32½ gallons
Area of farm	907 acres
Irrigable area	651 "
Area irrigated at one time	300 "
Gallons of sewage treated per acre irrigated per day	28,000 gallons
Gallons of sewage treated per acre of farm per day	12,900 "

Baker says in his "British Sewage Works" that, when visited by him, in 1904, the dry weather flow had increased to 10.8 million gallons per day and the total area of the farm was 1,950 acres, of which 1,300 acres were irrigable. About 120 acres of this were held in reserve for emergency use.

The first 636 acres were leased in 1878 at $24.30 per acre annually for 65 years. Since then all but 173 acres of the holdings in 1904 had been bought by the city at an average gross cost of $583 per acre. The farm was first operated in 1880.

The combined system of sewerage is used. About 3/7 of the flow is trade waste from bleaching, dye and wool scouring works, breweries, etc., but the amount of solid excreta is not large owing to the fact that many of the dwellings are not connected with sewers. Storm water is admitted to the sewers up to a rate of ¼-inch of rainfall per day.

The soil is generally of light sandy loam, 7 inches to 15 inches thick, overlying and interspersed with gravel and sand. This is all underdrained at a depth of from 4½ to 7½ feet.

About half the irrigable area is irrigated at one time and some 50 acres of this, closely underdrained, is in continuous operation for a month or so, until overdosed. The balance is divided into two parts, each of which receives sewage 12 hours in alternation with the other.

The staple crops are Italian rye grass, mangel-wurtzel, ox cabbage, kale and kohlrabi, but during years when not irrigated there are grown clover, cabbage, grain, potatoes and turnips.

There are also kept 620 head of cattle, including 92 milch cows, 620 sheep, 320 swine and 130 horses.

The gross revenue is about $78,000, of which about $11,000 is from the sale of milk.

The force required to work the farm comprises 110 men and boys whose wages amount to $19,400 per annum. The boys start in at $1.46. The wages shown in Table LXVI are paid per week in addition to the use of a house and garden:

TABLE LXVI

WAGES PAID ON THE SEWAGE FARMS

	Foreman	Labor
Ordinary work	$6.32	$4.13
Milkers	6.32	4.62
Wagoners	7.29	4.86
Engineers (for agricultural machines)	9.72	6.07

For the first 22 or 23 years of operation there was always a revenue over and above operating costs amounting to over $12.00 per acre but the next year being unusually wet there was a loss. The favorable showing appears to be due mainly to the excellent condition of the soil and to the especially efficient superintendence of the farm.

PASSADENA

In the United States the Passadena farm has been perhaps the most profitable. Three hundred acres were bought in 1887 for $40,000 and 150 acres more in 1904 for $9,000. In the year 1903-4, 840,000 gallons were received on the land which was planted with alfalfa and walnuts. Later, alfalfa was given up as unsuitable. The operating expenses were $6,310.91 and the revenue $11,643.57 ($7,847.29 of which was from the sale of walnuts). Even with $1,400 added to the expense account, for interest at 3½ per cent., there remained a profit of over $3,900, or about $13 per acre. In spite of this apparent profit, the farm has now been abandoned for other means of disposal.

American and European Conditions Compared

There are many reasons why sewage farming is not so well adapted to American as to European conditions. In the first place, the water consumption per capita being twice that of European cities, the land required under conditions otherwise similar is also twice as great and so twice as costly. The price of labor, too, is much higher in America than abroad, and as about twice as many men are required per acre as on an ordinary farm; this places sewage farms in America at a disadvantage. Finally, political conditions are less favorable here. For successful farming and to secure sanitary results, the city should control the application of the sewage. The Royal Commission on Sewage Disposal has placed itself on record as against the practice of losing control by leasing farms devoted to sewage irrigation. This means municipal operation, often on a large scale, with all the uncertainties connected with the changing and decentralized administration of our American cities and the opposition of those with whom the sale of the products would bring the city into commercial competition.

It is important that the peculiar difficulties to be met should be fully appreciated before committing a town to the adoption of sewage farming. They include (1) the cost of land near cities and its equipment (which has been estimated at five times that of an ordinary form), (2) the character of the land, (3) the penetration of frost in soils otherwise favorable, (4) the removal and disposal of the coarse solids, (5) the possibility of unpurified sewage finding its way to a water supply, (6) the possible infection of cattle feeding on sewaged grass, (7) the possibility of odors permeating the atmosphere in warm, damp weather, (8) the problem of procuring adequate and efficient superintendence and labor, (9) transportation and sale of crops.

Financial Results

Among the most complete financial figures are those given by the Royal Commission on Sewage Disposal in their Fifth Report. These are based on a million imperial gallons of "normal domestic" sewage per day from 25,000 persons on land at $484 per acre and labor at $5.11 per week. It is assumed that the sewage is collected by the combined or partially separate system and the last includes preliminary sedimentation and the disposal of sludge as well as the cultivation of the farm.

The areas required under different conditions, gross cost and receipts are given in Table LXVII from the Fifth Report of the Royal Commission.

TABLE LXVII

Data, Cost and Returns from Sewage Farms in England

Nature of Soil	Process	Gallons Settled Sewage per Acre Daily	Total Acres dwf.* in Mgd.**	Gross Cost per Mgd.**	Receipts per Mgd.**	Net Cost per Mgd.**	Cost per Capita
Sandy loam overlying gravel and sand...	Filtration with cropping..............	14,400	70	$13.71	$1.38	$12.33	17.7c.
Sandy loam overlying gravel and sand...	Filtration with little cropping..........	30,000	33	10.02	.65	9.37	13.7c.
Sandy loam overlying gravel and sand...	Surface irrigation and cropping..........	8,400	126	16.89	2.40	14.49	21.3c.
Heavy soil overlying clay.............	Surface irrigation and cropping..........	6,000	167	24.34	3.30	21.04	30.9c.
Stiff clayey soil over dense clay........	Surface irrigation and cropping..........	3,600	280	34.56	5.52	29.04	42.5c.

* Dwf. = dry weather flow. ** Mgd. = million imperial gallons per day.

Under the conditions assumed, it was estimated that irrigation would be cheaper than tank treatment followed by percolating filters where the soil was light and porous, but not otherwise. The conditions are subject to wide variation. The larger the area, the greater the cost, but, with good management, the larger the area the better the prospect for a profit.

In the 21 towns whose returns from sewage irrigation are enumerated in the table just given, there are about 8 whose income exceeds their operating expenses and there is none showing a net profit after deducting loan charges. This does not mean that many of these farms have not been an economically wise investment. That point can only be decided by comparing their cost with the cost which would have been incurred for disposal by other methods.

Analyses thus sets at rest the popular notion that sewage farming is profitable as a purely business venture. As stated by the Royal Commission, quoted by Scoble in his work on "Land Treatment of Sewage": "Although we are of opinion that sewage farms in general can never show a profit, if interest on capital expenditure is included, the fact that in favorable seasons some of them can more than cover the working expenses is a point in favor of cropping."

AUTHORITATIVE OPINIONS WITH REGARD TO IRRIGATION

It is a notable fact that of all the authors of recent treatises on sewage disposal, not one is favorable to irrigation except in situations where unusual opportunities for this kind of disposal occur.

Dunbar, in his "Principles of Sewage Treatment," London, 1908, page 115, says:

"It will have been noted that the results of irrigation from a sanitary point of view are influenced by many factors, some of which it is impossible to control and yet, in spite of this, irrigation is still regarded as the best method of sewage purification. Its application as a method of raising crops is only possible, generally speaking, at the expense of the purification. It has, however, been generally recognized that profits cannot be obtained from sewage irrigation. Contrary opinions, which are held by imaginative persons, but not supported by actual observations are continually cropping up and being urged with the ardor of prophets. They may, however, reasonably be neglected here."

Again, page 109:

"More recently the value of domestic sewage as a manure has been usually estimated at four to five shillings per head per annum. Hence, by a rational use of its domestic sewage, a town of 100,000 inhabitants might reasonably expect an income of nearly $125,000 per annum from its sewage. Even without taking into account the preparation of the land and the cost of conveying the sewage, but simply considering the working costs, such incomes have nowhere been obtained. No case is known which shows a profit from irrigation, when subjected to a strictly commercial investigation."

Rideal, in his book on "Sewage and the Bacterial Purification of Sewage," says: "With careful management the sale of produce from a sewage farm may be made to yield a small balance over working expenses, but not sufficient to repay the capital, which is estimated to be about five times that required for an ordinary farm."

"The chief objections to land filtration have been summarized as follows:

"1. Generally the worst part of the sewage—the sludge—is not dealt with at all.

"2. As crops are usually grown, their cultivation is often considered, by those left in charge, as more important than the purification of the sewage, and so the latter is not fully treated except where irrigation is of advantage to the crops.

"3. Unless the land receives very careful attention, a bad result is generally produced from even the best farm and it is difficult for anyone but a highly trained man to keep the works under proper control.

"4. There are many possibilities whereby land which has been laid out carefully may fail, even with careful working, such as the cracking of the land, admitting crude sewage into the drains without filtration.

"5. Land of sufficient quantity or quality, and at a reasonable price, is often unattainable."

In their work on "Sewage Disposal," New York, 1910, p. 207 et seq., Messrs. Kinnicutt, Winslow and Pratt say:

"On the whole, it may be said that a sewage farm under the best conditions, may yield a better effluent than that which can be obtained from contact beds or trickling filters. Where the soil is heavy, however, the results of irrigation are very much inferior to those which can be attained by the so-called 'artificial' processes. Furthermore, in sewage farming there is always a tendency to the by-passing of surplus sewage at times of rain, and in many instances this militates seriously against the general efficiency of the process.

"* * * It is of course obvious that well waters in the neighborhood of irrigation areas must be subject to strict supervision * * *.

"The economic advantages of sewage farming have long been a debated question. The utilization of waste products is always an attractive idea; and sewage fields covered with a rich mantle of luxuriant vegetation make a strong appeal to the imagination. It has been said, however, that it is poor economy to save something by a process which costs more than the value of what is to be saved.

"With fair soil and not too heavy rainfall, broad irrigation may be operated satisfactorily by cities having at their doors large areas of cheap and unfertile sandy soil. Its economic value then depends upon a number of minor variables. The cost of land, the cost of labor, the available markets and, above all, the skilful management devoted to the farms chiefly control the final result.* * * Sewage farming is not likely to be one of the future activities of the American city except in arid regions."

In his treatise on "Sewage Disposal," New York, 1912, George W. Fuller has said, p. 595 et seq.:

"Strictly speaking, this method is not in general use in this country except in the Far West, although there are some intermittent sand filter plants in the East where crops are raised on portion of the area. Some profit results from the use of these filter areas for agricultural purposes, but this seems to be a small and incidental feature * * *.

"Many references in technical journals can be found to the use in the West of broad irrigation as a means of sewage disposal. But the facts usually show that such use was merely incidental and not entitled to serious consideration from the sanitary standpoint.

"* * * When the sewage is not considered helpful for agricultural uses, there is altogether too great a tendency to divert it to some neighboring stream bed. This difficulty has been regulated properly in some of the large European plants, but it requires the constant and careful effort of a competent corps of inspectors and patrolmen. Otherwise the sanitary requirements as to sewage disposal become entirely subservient to the interest and convenience of the farmer.

"* * * Objections to the method have increased rather than decreased in recent years. These relate to objectionable odors, prejudice against the use of sewage in growing vegetables and to the transmission of disease germs by flies and other insects.

"Experience shows that only nominal aid financially has been received from the use of sewage in broad irrigation."

The book on "British Sewage Works," New York, 1904, which was published by M. N. Baker, after visits to the principal sewage disposal plants of Europe, contains descriptions of various sewage farms in England and those of Paris. Mr. Baker, after seeing what were considered to be the best managed sewage farms in Great Britain, remarks, page 104 et seq.: "For some years past nearly all the printed matter relating to sewage disposal in Great Britain has either contained no reference to sewage farms or else spoken of them as being abandoned as rapidly as possible."

On page 114 Mr. Baker says: "As a rule, the purely natural conditions in many sections of the United States are far more favorable to sewage farming than they are in England, but nearly all other conditions, and they are many, are against the practice. We have fortunately never been carried away by the glowing claims of prophets for sewage farming, although not infrequently they are urged by well meaning but ill-informed persons."

Among the foremost scientific authorities who have considered the subject of sewage disposal from the agricultural standpoint is Prof. F. H. Storer of Harvard University, in whose book on "Agriculture in Some of Its Relations With Chemistry," seventh edition, New York, 1910, is an extended notice of this subject.

Barwise, in his book on "The Purification of Sewage" (1899), disclaims any real superiority in sewage farming as a means of conserving the fertilizing ingredients. He says: "When we bear in mind that leguminous plants have the power of absorbing nitrogen from the air and that the sea requires its nitrogen replenished, on account of the fish taken from it, the fallacy of the manurial-value argument becomes too ridiculous to entertain for one moment."

An adverse opinion of its value is that of Tidy in his "Treatment of Sewage" (1887). He says: "The effect of all the constituents of a manure is but the effect of that one of them which, in comparison with the wants of the plant, is present in smallest quantity." Therefore artificial fertilizers are usually required to supplement the deficient potash or else the ammoniacal and phosphoric acid compounds, which are in excess, are left to clog the soil. Moreover, while the crops absorb from 40 to 75 per cent. of the nitrogen from the ammonias of the sewage, weak sewage, such as are often found in the United States, may, if applied in excessive amounts, actually remove valuable manurial salts from the soil by solution.

Another person has said that it would be as reasonable to expect farmers to manure their land with the smoke of cities as with sewage, for, as everyone knows, enormous quantities of ammonia must be lost in the aggregate in cities where domestic fires are fed with coal.

Professor Storer considers that the problem of how to dispose of the sewage of a city is simply a sanitary question. The danger of exhausting the fertility of the soil by continued cropping without restoring the nitrogen and other available compounds by means of manures or artificial fertilizers is by him regarded as too remote for consideration. If the land requires enrichment, the use of artificial fertilizers is capable of supplying all that will be needed. The present sources of the ingredients of fertilizers are practically inexhaustible and other sources will doubtless be discovered when needed. There seems to be no reason why agriculturalists should feel the need of the nitrogen of sewage since every farmer who lives within reach of railroads or steamboats has the whole world from which to draw his supplies of manure.

In Professor Storer's words:

"No matter how freely it may be admitted that immense quantities of plant food are carried out from the city every year through the sewers, it remains none the less true that these fertilizing matters are carried out in a state of such extreme dilution that it is idle to talk of recovering any of them economically in the present condition of labor and commerce or of utilizing the sewage in any way excepting in arid regions and in some rare localities."

Lawes has stated the views of English experts in a paper on "The Disposal of Sewage by Some Towns and Villages" in the Journal of the Royal Agricultural Society of England, Series 3, Vol. I, 1890, page 86, as follows:

"Now that the sewage question has been through the wild extravagance of its early days and sewage has come to be regarded by all sensible people as a nuisance to be gotten rid of rather than being in itself a mine of wealth, the solution of the problem has become an easier matter. The primary question is no longer how to extract the small amount of fertilizing matter it contains, with the idea of making a fortune by sewage farming or a valuable artificial manure, but how to rid ourselves of the sewage that it may do the smallest amount of harm at the least possible cost."

In Dr. Tidy's opinion, "The story of one and all sewage farms is a history of commercial failure."

CONSIDERATIONS AFFECTING NEW YORK

As mentioned in Preliminary Report I of the Metropolitan Sewerage Commission, September, 1911, page 5, the sandy soil of Long Island lying east of Greater New York between Amityville and Quogue is the only region where it would be at all practicable to treat the great volume of the city's sewage, or any large part of it, by irrigation. This volume, which will reach 1,330 million gallons by 1940, would require about 175 square miles for treatment, allowing 12,000 gallons per acre.

Leaving out of account the cost of the land the project is estimated to cost $152,780.00.

It would be more reasonable for the sewage of parts of Brooklyn and Queens to be applied to farm lands. Aside from the financial argument which would probably be conclusive, there are the other considerations that have already been referred to as drawbacks to irrigation in the United States, viz.: possible nuisance, possible contamination of the sources of well supplies, value of the land for building purposes and the uncertain effect of taking over a great agricultural enterprise by the municipality with all its possibilities of inefficiency due to the short terms of office of those in control.

RECENT OFFICIAL OPINIONS ON UTILIZATION

Two reports on the utilization of sewage appeared in December, 1913, one in England and one in the United States. Each was brief but well calculated to show the opinion of its author. The author was in each case qualified in every way to form an authoritative opinion with respect to the subject dealt with.

Dr. MacLean Wilson is Chief Inspector of the West Riding of Yorkshire Rivers Board and in this capacity directs the efforts which are being made by a rural and urban population of over 3,000,000 persons located in the center of England to dispose of this sewage in a sanitary manner and at the least practicable cost.

Mr. H. W. Clark is Chemist of the Massachusetts State Board of Health and in charge of the Lawrence Experiment Station where a larger and longer experience has been had in the disposal of sewage on an experimental scale than has been enjoyed elsewhere. All efforts made in the State to dispose of sewage come under his critical examination.

Dr. Wilson's opinion is set forth in an official report of the West Riding of Yorkshire Rivers Board; Mr. Clark's in a monthly bulletin of his Board.

Opinion of Dr. H. MacLean Wilson. In Dr. MacLean Wilson's opinion, the use of water carriage for the removal of the sewage has greatly added to the difficulty of making use of the fertilizing materials. The wastes from each adult inhabitant, estimated at about $2.62 per annum, are diluted by 7,000 imperial gallons of water and to extract the material which theoretically is worth $7,500,000 would necessitate dealing with 22,000 million gallons.

In practice, Dr. Wilson shows that, owing to the difficulty of obtaining suitable land within reasonable distance of towns and owing to the necessity for dealing continuously with huge volumes of water of which the sewage is composed, it is impossible to utilize the sewage profitably in farming except under rare circumstances, and nearly all the large towns in England have found it necessary, because of the cost, to abandon the use of their sewage farms and adopt more modern methods of sewage purification.

Dr. Wilson states that inasmuch as more than half the valuable constituents of sewage are in solution, unless purification is accomplished by means of land treatment, this portion escapes into the streams and is lost, so far as utilization is concerned. The idea of discharging sewage effluents into fish ponds to encourage aquatic vegetation and so favor the growth of insects, crustaceans and other forms of life upon which fish thrive does not seem practicable to Dr. Wilson as a general procedure. To him it appears necessary to face the probability that about one-half of the intrinsic value of the sewage, the whole of which is estimated in his district to be worth about $7,500,000 yearly, must be allowed to escape to the streams without utilization.

That part of the sewage which can be utilized consists in the sludge which is recoverable by screening and especially by sedimentation. Before it can be used Dr. Wilson states that the sludge must be dried either by filters, so as to contain about 70 per cent. of water, or by means of sludge presses to the form of a thick solid cake, in bulk one-quarter of the original volume and in water about 60 per cent. In either case it is in condition to be removed in carts and spread over land by spade. In a few towns the sludge is dried still further so that it can be ground up and sold in the form of a powder.

Dr. Wilson describes the "Globe" fertilizer produced at Glasgow, the product at Kingston-on-Thames or native guano, the Bradford process, the Oldham method of drying by means of heat and removal of grease by distillation, all of which are described elsewhere in the present report of the Metropolitan Commission. Reference is also made of Hebden Bridge, where the sludge is sold in a granular form obtained by drying the pressed cake and passing it through a disintegrator and Huddersfield where a new apparatus has been installed for wet-carbonizing and pressing the sludge, extracting the grease by means of a solvent and reducing the sludge finally to an impalpable powder.

In the West Riding of Yorkshire over 500,000 tons of pressed or filter-dried sludge, containing 60 to 70 per cent. of water, are produced annually. Dr. Wilson's report states that if the sludge is used as a top dressing for grass land, it is found that the grease does not permit the sludge to weather and break down sufficiently rapidly and that even after many months it lies in lumps apparently unaltered. If ploughed or dug into the soil, a still longer time is required for it to become assimilated with the humus around it and, if used in large quantities, it clogs the pores of the soil or prevents the percolation of air and moisture which are so important to plant life. Moreover, the sludge is likely to contain seeds of nettles, docks and other troublesome weeds, not to speak of tomatoes, raspberries, strawberries and other fruits, whose plants spring up in thousands around the sludge beds.

Notwithstanding its drawbacks, the sludge forms a valuable manure for certain soils and purposes and, considering its low cost and plentiful supply, should be more frequently used. Dr. Wilson suggests that a good way to use sludge is to make it into the form of a pie with alternate layers of farmyard manure and to let it ripen for months, after which it can be used for top dressing or ploughed into the soil. This is after the plan of composting, elsewhere referred to in the present report of the Metropolitan Sewerage Commission.

According to Dr. Wilson, the manurial value of sludge does not vary greatly whether it comes from a town where the houses are nearly all provided with water-closets and the sewage therefore contains all the excreta of the inhabitants, or from a town where all the houses have dry closets and the excreta are not discharged into the sewers. This fact is shown by a table supplied by Dr. Wilson, containing the results of analyses of the sewage of about twenty towns. From the figures given, it appears that sludge containing 70 per cent. of moisture is worth about $1.75 per long ton, calculated on the basis of nitrogen, phosphoric acid and potash present, assuming that the whole of these ingredients are present in available form and estimating their prices from those of sulphate of ammonia at about $60; superphosphate at about $13, and sulphate of potash at about $48 per ton.

In Dr. Wilson's opinion the most substantial reasons for the unpopularity of sewage sludge as a manure rest upon the unmanageable form in which the sludge is usually offered for sale and the presence of the relatively large amount of grease which it contains. It has repeatedly been found in England that when sludge is dried and broken up into a coarse powder, it commands a ready sale, either by direct use by agriculturists or to be strengthened by the addition of fertilizing compounds. When the moisture is reduced from 75 per cent. to 25 per cent., as it must be in order to produce the powder from pressed or filtered sludge, the bulk is greatly diminished and the material has a correspondingly increased commercial value.

The economical removal of the grease from the sludge is a problem which Dr. Wilson finds has not been solved, although its solution has been attempted on different lines at various places.

In general, the removal of the grease necessitates, first, the removal of the water and then the application of heat which has the agricultural advantages of sterilizing the disease germs and destroying the seeds of hurtful weeds, besides making it a comparatively easy matter to reduce the sludge to the form of a powder. The removal of the grease facilitates the use of the sludge in agriculture, for the material can then be applied to the land, either as a top dressing or ploughed in, in either event the material breaking down readily and becoming assimilated with the soil. Dr. Wilson reports an increased demand for this manure.

Taken as a whole, Dr. Wilson's report takes a hopeful view of the possibilities of utilizing that part of the valuable ingredients of sewage which can be extracted in the form of sludge. An early solution of the problem lies, in his opinion, in the fact that there are many capable experimenters at present at work in the effort to prevent the waste at a cost which will permit the sludge to be prepared and transported in a condition profitable for the agriculturist.

Opinion of Mr. H. W. Clark. After reviewing the efforts made by different cities in Germany, England and America to make use of their sewage since the middle of the last century and making some estimates of the manurial value of sewage based on the composition of the fairly strong domestic sewage of the City of Lawrence in 1912, Mr. Clark concludes that the total amount of fertilizing and fatty matters in each 1,000 gallons of representative American sewage is not worth over 6 or 8 cents. Of this, about half is represented by the ammonia in solution and there is no method by which it can be utilized except by application to land.

Experience covering many years, with hundreds of well-operated sewage farms, has convinced Mr. Clark that only under the most favorable conditions can a return from farming be made to pay the operating expenses and there is no instance wherein the returns both pay the cost of operation and interest on the capital invested, except in regions of low rainfall, where the liquid is useful for irrigating purposes.

Mr. Clark estimates that average American sewage contains about 2,400 pounds of sedimentable matter in a million gallons and that the nitrogen, fats, etc., in this material are worth about $15 to $18. In order to reclaim the useful material, he points out that the solids must be removed, dried, pressed and subjected to a process for the separation of grease from the fertilizing constituents, for only by this separation can the grease become an article of commerce and the fertilizing constituents be of real agricultural value. Only in a few places is the separation of the grease attempted as a commercial enterprise and the profitableness of these works is doubtful.

After the sludge is practically freed from its fats, it consists, in a large part, Mr. Clark says, of inert mineral and organic matter mixed with a comparatively small weight of fertilizing materials and consequently the cost of carriage is great even when the sludge is well dried.

Mr. Clark considers that it is well proved that the nitrogen, phosphatic acid, etc., are generally in less assimilable form than are the same bodies in ordinary commercial fertilizers. The opinion, expressed by Mr. Clark as the result of his study, is that the sludge has some value and as the processes of drying, pressing and fat separation are improved and as nitrogen advances in price, it seems to him inevitable that sewage sludge will become of greater agricultural value than it is at present, especially as the basis of fertilizers enriched by the addition of potash, phosphates, etc.

SLUDGE

When the normal flow which is customarily maintained in sewers in order that they shall be self-cleansing is checked and the sewage comes to a state of more or less complete rest, a deposit forms which is termed sludge. This deposit is so easily obtained and the removal of the sludge is such a useful step toward the purification of sewage that sedimentation has become an almost invariable part of disposal works.

Sludge is a mixture of particles of various degrees of density ranging from fine sand and fleshy substances of animal and vegetable origin to particles in a semi-liquid condition. Semi-solid matters called colloids are characteristic of sludge. They contain a large proportion of water which they part with only with much difficulty. In order that the water may be removed, it is necessary to change the physical condition of the colloid particles. This can be done by heat and by fermentation. On exposure to the atmosphere and by providing free drainage, the water is removed with great difficulty.

The density of sludge depends upon many factors, including the composition of the sewage from which the sludge was derived, the length of the period afforded for settlement, the length of time during which the sludge was stored and its accessibility to air or oxygen in the water or sewage which happens to be overlying the sludge.

Sludge, when fresh, is usually dark in color, of unpleasant odor and of a consistency resembling thin mud. It becomes more dense and pasty with drying. It can be pumped, but it cannot well be shoveled until it has parted with about one-third of its moisture.

Oxygen generally does not have access to the interior of sludge masses for the reason that free circulation does not occur and active anaerobic decomposition soon begins under ordinary conditions of temperature. If the sludge is overlaid with sewage, ill-smelling gases may be produced in large quantity and these escape at the surface in the form of bubbles. The odors are largely due to the formation of sulphuretted hydrogen and to organic gaseous compounds of complex nature.

If the sludge is permitted to ferment with little or no sewage over it, odors are to a great extent prevented. Anaerobic decomposition will not long proceed in a mass of sludge unless provision is made for stirring it or otherwise causing a circulation. A barrelful of sludge may remain with little apparent change in its physical condition for many months. If, however, small amounts of sludge are added at frequent intervals and the fermented product removed from time to time, vigorous fermentation may occur and the entire mass markedly change in physical composition.

In the fermented state the sludge is charged with gas bubbles, the peculiarly gelatinous state of the colloid particles disappears and a large amount of the contained liquid can be freely drained away. Well fermented sludge is inoffensive and incapable of producing objectionable odors; it resembles humus or garden mould in many respects.

The objectionable gases which arise from unfermented sludge may be diminished in volume by the addition of iron and various other chemical compounds to the sewage. A small amount of iron is always present, this element being well-nigh universal in nature. When sewage or sludge decomposes in the absence of oxygen, it is chiefly a combination of the iron and the sulphur which causes the mass to become black.

Chemically precipitated sludge contains not only all the solid and semi-solid ingredients commonly found in ordinary sludge, but considerable quantities of the precipitating agents and much colloid matter as well. The chemicals may or may not produce a restraining effect upon the behavior of the sludge in respect to fermentation, depending upon their character and amount. They may facilitate filter pressing, but they have the disadvantage of greatly increasing the bulk of the sludge produced.

CHEMICAL COMPOSITION

The analyses shown in Tables Nos. LXVIII to LXX give the chemical composition of some sludges obtained in various places in the United States and Europe by plain sedimentation and chemical precipitation. They also give the composition of fresh and septic sludge and the product of septic tanks and Emscher tanks.

TABLE LXVIII

PERCENTAGE COMPOSITION OF FRESH AND SEPTIC SLUDGE*

	Fresh	Septic
Volatile solids	45.8	32.6
Fixed solids	54.2	67.4
Nitrogen	2.0	1.3
Carbon	27.9	19.5
Fats	15.8	8.0

TABLE LXIX

SLUDGE FROM EMSCHER TANKS

City	Of Dry Residue				
	Moisture	Mineral	Organic	Nitrogen	Fats
Philadelphia[1]	82.5	62	38	1.2	6.5
Chicago[3]	[2]88	61	39		
Recklinghausen[4]	82.9	54.7	45.3	1.74	6.87
Essen[4]	75.6	45.1	54.9	1.22	4.95
Bochum[4]	78.1	61	38.1	1.18	6.12

TABLE LXX

SLUDGE FROM CHEMICAL PRECIPITATION

	Dried at About 110° C.				
	Moisture	Mineral	Volatile	Nitrogen	P_2O_5
Kingston—Native Guano[5]	25.67	36.14	37.99	1.93	1.74
Dorking—Lime and Alumino-ferrio[5]	37.67	37.52	24.81	.89	0.66
Chorley—Alumino-ferrio[5]	12.50	50.74	36.76	1.28	0.98
Leeds—Alton's Process[5]	22.06	30.67	47.27	1.04	2.12
Glasgow—Globe Fertilizer[5]	22.51	43.51	33.98	1.30	1.11

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[*] Sewage Disposal, p. 142, Kinnicutt, Winslow & Pratt.
[1] Report on Sewage Test. Sta. 1911; [2] 86 to 90; [3] Report Geo. M. Wisner, Sanit. Dist. Chicago.
[4] Sewage Sludge, p. 180.
[5] Report Royal Com. Sew. Disp.
V. App. VIII, p. 9.

VOLUME AND WEIGHT

In general it may be said that plain sedimentation will produce from 4 to 7 cubic yards of sludge of from 87 to 93 per cent. moisture; septic tanks 1.5 to 3 cubic yards of from 80 to 90 per cent. moisture; Emscher tanks 1 to 2.5 cubic yards of from 75 to

85 per cent. moisture, and chemical precipitation tanks 20 to 25 cu. yds. of from 86 to 92 per cent. moisture per million gallons of sewage. Some examples are given in Table LXXI.

TABLE LXXI

Per Cent. Moisture Produced by Plain Sedimentation, Scientific Treatment and Chemical Precipitation

	For Plain Sedimentation*	
	Cubic Yards per Million Gallons	Cubic Yards per 1,000 Population Daily
Frankfurt	16.3	.930
Bremen	10.9	.655
Hanover	9.9	.301
Mannheim	10.9	.877
Cassel	23.8	.628
Reading†	3.3	
Philadelphia‡	4.7 to 6.31	
	For Septic Treatment*	
Manchester	12.0	0.62
Accrington	7.9	
Hampton	4.36	
Birmingham	16.85	
Stuttgart	18.6	0.50
Merseberg	8.2	0.10
	For Chemically Precipitated Sludge§	
London	25.2	
Salford	45.6	
Leeds	19.4	
Sheffield	14.2	
Providence	19.4	
Worcester	24.3	

*Sewage Sludge, Elsner, Spiller, Allen, pages 18-19.
†Sewage Sludge, Elsner, Spiller, Allen, page 217.
‡Report on Sewage Testing Station, Bureau of Surveys, Phila., 1911, page 161.
§Sewage Disposal, Fuller, page 93.

Koelle** gives for Frankfort, with 92,000 inhabitants, 335,000 cu. m. of sludge or 274 cu. yds. per 1,000 persons. Dunbar estimates that the weight of sludge produced per year from the sewage of 1,000 persons will be 110 tons by plain sedimentation and three times this amount by chemical precipitation.††

As to weight, undecomposed sludge and chemically precipitated sludge are taken to have the weights given in Tables Nos. LXXII and LXXIII.

**Guide to some of the public works to Frankfort-on-the-Main—Koelle.

††Principles of sewage treatment, Dr. Dunbar and H. T. Calvert, 1908, page 262.

TABLE LXXII

Weight of Chemically Precipitated Sludge*

	Tons per Million Gallons	Moisture, per cent
Strong European sewages	25–35	90
American	15–20	90
London sewage	30	91
Worcester sewage	20.6	93
Providence sewage	16.5	91.6

TABLE LXXIII

Approximate Weight and Volume of One Cubic Yard of Wet Undecomposed Sludge†

Per Cent. Moisture	Specific Gravity					
	1.02		1.04		1.06	
	Pounds, per Cubic Yard	Cubic Yards Per Ton	Pounds, per Cubic Yard	Cubic Yards per Ton	Pounds, per Cubic Yard	Cubic Yards per Ton
100	1685	1.190	1685	1.190	1685	1.190
95	1700	1.176	1720	1.163	1735	1.149
90	1720	1.163	1755	1.136	1785	1.124
85	1735	1.149	1785	1.124	1835	1.087
80	1755	1.136	1820	1.099	1905	1.053

*Sewage Disposal—Kinnicutt, Winslow and Pratt, page 167.
†Sewage Disposal—Fuller, page 447.

Disposal of Sludge

The simplest and most satisfactory methods of disposition are irrigation and air drying.

Irrigation with Wet Sludge. The wet sludge may be applied directly to the land in a way similar to sewage irrigation. It can be run into trenches, covered with 2 or 3 inches of soil and the land used the succeeding year or two for cultivation. The size and arrangement of the trenches depends largely upon the absorptive properties of the soil. Under favorable conditions trenches may be 2 or 3 feet wide, 12 to 20 inches deep and about 5 feet apart.

At Birmingham about 3,000 lin. ft. of trench 3 ft. wide on top and 18 inches deep were required daily to dispose of 1,000 short tons of sludge (94.5% moisture). By cultivation during the intervening time the operation could be repeated in from 18 months to 2 years.

The Royal Commission on Sewage Disposal estimates the area required as shown in Table No. LXXIV.

TABLE LXXIV

Area Required for Disposing of Sludge by Irrigation

	Tons 90% Water per Million Gallons	Area Required per Million Gallons Daily—Acres
With plain sedimentation (continual flow)	10.1	3.68
With septic tanks	6.0	2.17
With chemical precipitation (continual flow)	14.7	5.32

General figures relating to sludge should be used with caution, as much depends on the climate, the character of the soil and its treatment, and the character of the sludge, aside from its moisture.

The disposal of sludge by burying is often preceded by allowing it to flow upon drying beds and into lagoons in order to reduce the water content; in this way some saving is effected in the land required for the final disposition. In many cases lagoons and drying beds afford all the preparation which the sludge receives before it is disposed of by dumping upon low-lying land. The figures shown in Table LXXIV apply particularly to treatment on drying beds and in lagoons preparatory to removal for the final disposition.

The time of drying depends on the composition and condition of the sludge, the amount of water present, facilities for drainage, the exposure of the sludge to the weather, humidity and wind.

To be spadable, sludge must not contain much over 60 or 70 per cent. of moisture. Plain settled sludge usually requires 6 to 8 weeks in summer and 6 months in cold weather and septic tank sludge takes 2 weeks in good weather and Emscher tank sludge usually about 5 days to dry to this state under favorable conditions.

About one acre per million gallons of sewage is a fair allowance for sludge drying.

It may be said, in general, that there is no revenue to be expected from any of these methods of air-drying. If plenty of suitable land is available, there will be a certain economy in using the sludge so dried as a fertilizer, but no results comparable with those obtained from artificial fertilizers can be looked for, and this method is usually only applicable to small plants. There are several reasons for this. In order to be efficiently used as fertilizer, the sludge should be furnished only as required. The large volume of moisture which fresh sludge contains renders initial drying desirable and in this case there is expense for handling. The grease contained also prevents the useful ingredients of sludge from being readily assimilated.

Unless derived from septic or Emscher tanks or buried in trenches, there is almost certain to be an evolution of foul gases and odors and the nuisance of flies, besides which the liquids draining off are so offensive as to require treatment. Mr. Watson has found bleach useful in preventing the occurrence of odors and flies at Birmingham. He has applied it at the rate of 30 lbs. of bleach containing 36.35 per cent. available Cl per 100 cu. yds. of sludge. At Biebrich, Germany, from .1 to .2 gallons of "facilol," and at Frankfort from .1 to .2 gallons of "facilol" per sq. yd. of exposed surface of sludge has proved effective. Facilol is an oil having a specific gravity equal to 0.79 and costs there 13½ cents per gallon. A covering of peat has sometimes been found to be a good deodorizer for sludge. At Cassell, 7 pounds of lime per cu. yd. of sludge was found a good preventive for flies although reducing the value of the sludge as a fertilizer. In spite of efforts made to the contrary, sludge beds almost always prove to be a nuisance.

The cost of air-drying septic sludge at Birmingham by spreading on land previously plowed is stated by the Royal Commission on Sewage Disposal in its Fifth Report to have been, for the Saltley Works, 2.67 cents per ton and for the Minworth Works, 2.40 cents per ton.

PRESSED SLUDGE

When it is desired to remove the greatest practicable amount of suspended solids and colloidal matter from sewage, recourse may be had to chemical precipitation. This process is particularly applicable to sewage which contains trade waste which makes it difficult to treat satisfactorily by plain sedimentation. The sludge obtained from chemical precipitation plants may be concentrated by pressure in filter presses in the form of cakes, the contained moisture being reduced to about 60 per cent.

The moisture contained in sludge cake can be reduced by air-drying and by heat. When kept protected from rain and sun, sludge cake remains inoffensive and, after air-drying, may be used for filling in land.

Sludge from plain sedimentation or when containing much grease cannot be readily pressed; in the former case passing through the filter cloths and in the latter clogging them. Even with sludge produced by chemical precipitation, it is often necessary to add 8 or 10 lbs. of lime per cubic yard of sludge before pressing. This adds to the cost of the process and increases the bulk to be disposed of.

It has been stated that septic or digested sludges may be pressed without difficulty, but evidence furnished the Royal Commission on Sewage Disposal and presented in its Fifth Report seems to refute this claim. Digested sludge, nevertheless, drains and dries with much less difficulty than does fresh sludge and less nuisance is caused by it.

The following are a few examples of works in which sewage sludge is pressed.

Worcester, Mass. Here the sewage contains much trade waste from wire mills, foundries and tanneries and is normally acid. The sludge, containing 92.4 per cent.

moisture, is first dosed with from 6 to 10 lbs. of lime per cubic yard and then subjected to a pressure of 80 lbs. per square inch. The cake produced in 1910, of 69.4 per cent. moisture, amounted to 3.7 tons per million gallons of sewage or 0.167 ton per cubic yard wet sludge.

Providence, R. I. The sewage contains wastes from wool washing, dyeing and bleaching establishments. In the year 1911, 4,657 million gallons were treated chemically, producing about 124,000 cu. yds. of sludge, or 26.6 cu. yds. containing 92.57 per cent. water per million gallons of sewage. Of this, 101,500 cu. yds. were pressed after the addition of 10.9 lbs. of lime per cubic yard of sludge. There are 18 presses; the pressure used varies from 60 to 80 lbs. per square inch. There were 28,819 tons of cake produced in 1911, which is equivalent to .284 ton per cubic yard of wet sludge.

Glasgow, Scotland (Dalmarnock Works). The sewage contains much trade waste from chemical, textile, iron, paper and cotton works, is variable in character and difficult to treat. The chemicals used for precipitation are lime, sulphate of iron, nitrate of soda and sulphuric acid. Two and three-quarter tons or 3¼ cu. yds. of sludge containing 90 per cent. moisture are produced per million gallons of sewage.* This is pressed to a state in which it contains 66 per cent. moisture.

Bradford, England (Esholt Works). Bradford is at the center of the English woolen industry and the sewage is very foul, containing large quantities of grease, soap and suspended solids. The following analysis of the sewage gives some of the principal ingredients in parts per million:

Suspended matter	800
Total organic matter	1,300
Organic matter in solution	670
Grease	440

The sludge is produced by treating the sewage with sulphuric acid, 3 long tons per million imperial gallons of sewage being the proportion of chemical used. When drawn from the tanks, the sludge contains 80 per cent. moisture. It is then passed through a ½-inch bar screen, heated by steam and pressed at 60 lbs. per square inch. One hundred and thirty-two presses are required to handle the 670 tons of wet sludge produced daily. The pressed cake has about 28 per cent. moisture and contains comparatively little grease, which passes off while warm with the drainage water.

Spandau, Germany. The daily flow of sewage to the Spandau plant is 2,400,000 gallons per day from 80,000 inhabitants; it includes some trade wastes. It is, according to American standards, a very strong sewage, containing over 1,000 parts per million of solids in suspension. It is treated as follows by what is known as the Degener process.

In the Degener process brown coal or lignite is first rough-ground, put through a fine grinding mill and then mixed with water. It passes to a tank where more water and sulphate of alumina are added and then by a trough with baffles to one of five vertical sewage settling tanks or towers of steel, each containing a conical baffle and a mechanically-operated stirrer. Sedimentation takes place in the steel towers, removing 90 per cent. of the suspended solids and producing 10.4 tons of sludge per million gallons of the original sewage. This reduces its moisture to 60 per cent. The sludge is then filter-pressed under a pressure of from 60 to 80 lbs. per square inch for 20 hours, after which it is removed to tip cars which are waiting. The sludge cake is practically odorless and from 1¼ to 2½ inches thick. There is a noticeable absence of odor about the plant and the effluent which passes to the river Havel is clear.

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*Sewage Disposal, Kinnicutt, Winslow & Pratt, p. 99.

Cost of Pressing. The cost of pressing sludge is usually combined with the cost of precipitation in consequence of which it is difficult to ascertain its cost separately.

At Providence, in 1910, the cost of precipitation was $3.11 and the cost of sludge disposal was $4.06 per million gallons sewage. The cost of pressing the sludge was $2.62 per ton of solids.

At Worcester, in 1910, the total cost of precipitation and disposal was $4.53 per million gallons of sewage or $3.88 per ton of solids.

At Glasgow, in the year 1911-1912, there were produced per million gallons of sewage 36.7 tons of wet sludge and 6.88 tons of pressed cake at a cost of $2.22 per million gallons of sewage or 39 cents per ton of cake.

At Spandau, the lignite (at $1.10 per ton) and the sulphate of alumina cost $8,400 per annum, $9.60 per million gallons of sewage and $0.94 per ton of wet sludge. The costs of operation are $21,500 per annum, $24.50 per million gallons of sewage and $2.35 per ton of wet sludge. About 6¾ tons of lignite and 1,600 lbs. of sulphate of alumina are required per million gallons. The cost per inhabitant per year is 33.1 cents.

The cost of pressing varies greatly, depending largely on the cost of the lime or other chemicals and the nature of the sludge. It also depends on the size of the plant. Experience in pressing has been more extensive in England than elsewhere, in consequence of which peculiar value attaches to the opinions reached by the Royal Commission on Sewage Disposal in regard to this subject.

Elsner gives the cost of pressing sludge in Germany as from 63½ to 85 cents per ton of cake; Reichle and Thiesing (without the addition of lime, but including fixed charges) 49 cents under favorable conditions, while Schiele estimates the cost under English conditions at from 42 cents to $1.28 per ton. According to Moore and Silcock, in their "Sanitary Engineering," the cost of pressing, per ton of wet sludge, is, exclusive of fixed charges, 24.2 cents at Manchester. According to Raikes, in his

"Sewage Disposal Works," a complete plant sufficient to press 33 tons per day costs in England about $3,900 and the cost of pressing varies from 7½ to 11 cents per ton of wet sludge or from 43½ to 54½ cents per ton of cake.

According to George C. Whipple, the value of pressed sludge is seldom equal to the cost of the lime and pressing. When taken by farmers it sometimes about pays for these charges, but otherwise there is a loss.

CENTRIFUGALIZED SLUDGE

Centrifugal machines for drying sludge require less space and auxiliary machinery than presses and have the further advantage of not requiring the addition of lime or heat for their proper operation.

A centrifugal sludge machine has been designed after much experimentation in Germany by Stadtbaumeister Schaefer of Frankfort. It is now in operation at Frankfort, Hanover and Harburg. In operation, the sludge passes through a 0.4-inch screen to an elevated storage tank, from which it is admitted to the rotating chambers of the machine. A period of 2½ to 3 minutes is required to complete the cycle of filling, dewatering and emptying the sludge. The product contains from 60 to 70 per cent. moisture. Once in about 10 minutes the interior of the machine is cleaned by flushing with water.

Hanover. The data contained in Table LXXV have been furnished by the manufacturers of the centrifugal machines used at Hanover.

TABLE LXXV

COST OF CENTRIFUGALIZING SLUDGE AT HANOVER

Population	280,000
Sewage per day	7,920,000 gallons
Wet sludge per day	130 to 195 cubic yards
Resulting dried sludge	2.62 to 3.92 cubic yards
Number of centrifugal machines	4
Cost, per Month	
Machinists (day and night shift)	$136.25
Laborers (for drying machines)	62.50
Coal (for gas generators)	82.50
Electric current (for lighting and for circulating pump)	40.00
Oil and waste-cleaning tanks, etc. (2 men in day shift)	43.75
Total, 30 days at $13.50	$405.00
From the above, we have—	
Cost per head of population daily	0.005 cents
Cost per million gallons of sewage	$1.70
Cost per cubic yard of wet sludge	6.88 to 10.3 cents
Cost per cubic yard of dried material	33.7 to 51.6 cents

Frankfort. At Frankfort there are 8 machines, each having a capacity of about 4 cu. yds. of wet sludge and turning out from 660 to 1,000 lbs. of dried product per hour. Six of these are usually in operation, two being held in reserve. They deal with 325 cu. yds. of wet sludge per day of 10 hours. The moisture is reduced from 90 per cent. in the raw sludge to from 50 per cent. to 70 per cent. in the product; the volume is reduced from one-seventh to one-fifth of the volume of the raw sludge. The cost of operation is from 9 to 15 cents per cubic yard of wet sludge.

These figures compare favorably with those for sludge pressing, especially when the cost of land, plant and chemicals and the volume of dried material in each case are taken into account; but the effluent is not so well clarified as when precipitation is resorted to nor is the moisture reduced to the same extent.

DRYING SLUDGE BY HEAT

Although sludge may be dried directly by heat, it is usually cheaper first to reduce the moisture to 50 per cent. or 60 per cent. either by pressing or centrifugalizing it. The object of drying is generally to reduce the bulk and weight so that the sludge may be transported conveniently and to prevent putrefactive changes. Sometimes the principal aim is to obtain a product that can be utilized more readily than crude sludge.

It is not common to dry beyond 50 per cent. moisture by pressing. Drying by heat is practiced at the Dalmarnock works at Glasgow, Scotland, at Bradford, Oldham, Norwich and Kingston, England.

At *Glasgow* the sludge cake is raised by an elevator and delivered through a chute to a dryer consisting of an inclined plate heated by a furnace. By an iron scraper shaped like the letter L, the material is gradually pushed down the plate to the lower end and then carried by a screw conveyor to a ¼-inch mesh screen which revolves on a horizonal axis. The screen is 36 inches long, about 18 inches diameter at one end and 24 inches at the other. The coarse material retained by the screen is conveyed to the hot inclined plate and passes over it again. The dried and screened material goes to a pug mill where it is ground to powder. It is then known as "Globe Fertilizer." Two analyses of this fertilizer given in the Fifth Report of the Royal Commission are contained in Table LXXVI.

TABLE LXXVI

COMPOSITION OF GLOBE FERTILIZER PRODUCED AT GLASGOW

	Per Cent.	Per Cent.
Moisture (at about 110° C.)	22.51	18.60
Volatile matter	33.98	35.20
Non-volatile matter	43.51	46.20
	100.00	100.00

The cost of producing Globe Fertilizer, excluding the cost of pressing, is $1.20 per ton.

At *Bradford* about a quarter of the sludge cake from the presses, or enough to supply the demand, is dried and sold to a fertilizer company. The cake is first broken up in a simple mill and is then dried from 50 per cent. to about 10 per cent. moisture in a rotary dryer. The dryer consists of two concentric horizontal steel cylinders. The sludge cake is fed to the annular space between the cylinders at one end and delivered in a dried condition to an elevator at the other end. The hot gases from a furnace enter the central cylinder at the same end as the sludge, are cooled from perhaps 1400° to 250° in the passage and return through the annular space containing the sludge. In the return the gases are cooled to 100° if forced draught is employed and the sludge heated to about 212°. The loss of heat in the exhaust is but about 7 per cent. and the efficiency of the plant, based upon the calorific value of the fuel, some 70 or 75 per cent. In a test lasting 96 hours the cost for fuel and labor was $12.94 or 33.6 cents per ton. If the first cost of the dryer is taken at $4,000, the fixed charges at 5 per cent. and the capacity at 40 tons of product per 10 hours, we may estimate the total cost per ton dried from 50 per cent. to 10 per cent. moisture, as indicated in Table LXXVII.

TABLE LXXVII

Cost of the Fertilizer Produced at Bradford

Operating costs:		
Coal at $3 per ton		38 cents
Stoker at 20c. per hour		5 “
Man feeding and delivering at 20c. per hour		5 “
Oil, Waste and Miscellaneous expenses		5 “
		53 cents
Fixed Charges	$\frac{4000x.05}{365x\ 40}$	2 “
		55 cents

The material as delivered is in the form of small pellets the size of pears which are inodorous and non-putrefactive.

Kingston-on-Thames. As stated in the Fifth Report of the Royal Commission on Sewage Disposal the sewage is treated with alumino-ferric, blood, charcoal and clay. The sludge is pressed, dried, passed through a sieve, dried further and is then known as “Native Guano.” The precipitation and sludge disposal cost 42½ cents per capita annually. Two samples analyzed are shown in Table LXXVIII.

TABLE LXXVIII

Composition of Fertilizer Produced at Kingston-on-Thames

	Per Cent.	Per Cent.
Moisture	25.87	10.19
Volatile matter	37.99	45.08
Non-volatile matter	36.14	44.73
	100.00	100.00

Destructive Distillation of Sludge

By raising the temperature of sludge sufficiently, the organic constituents can be volatilized, leaving the residue, which is largely mineral. This treatment is carried out at Oldham by a process known as Watson and Butterfield's Patent Sludge Distilling Process. The sludge dried so as to contain not over 20 per cent. of water, is put in a retort and heated to from 1500° to 1800° Fahr. The volatilized products are passed through a condenser and then through a scrubber which extracts the moisture, oil, tar and ammonia. The inflammable gas which remains is passed into the combustion chamber of the retort and there burnt. Steam is blown into the retort, near the bottom, and in passing through the hot zone in the retort it reacts on the carbonaceous material in the sludge, and in the presence of lime and at the high temperature there existing, the nitrogen in the sludge is evolved as ammonia.

The Royal Commission estimate the cost of pressing and burning sludge at Oldham, including fixed charges, at 32½ cents per ton of wet sludge (containing 90 per cent. of water) or, say, double the cost of pressing alone.

Production of Fertilizer

Elsner* gives the nitrogen and phosphoric acid in sludge as each comprising about 1.5 per cent. and the potash as 0.5 per cent. of the dried material of settled sludge. He estimates their theoretical value at—

28 cts. per cu. yd. of wet sludge (containing 90 per cent. water).
$1.10 per cu. yd. of dry sludge (containing 60 per cent. water).

Elsner also estimates that sludge to the value of $14.30 to $19.00 per day is produced by every 1,000,000 inhabitants, but points out that these figures are only possible theoretically. On the basis of 28 cents per cubic yard, as above, and an output of 0.786 cubic yards daily for each 1,000 persons, he estimates that an annual revenue of $78.50 could be derived from the utilization of sludge which would cover a part or, in exceptional cases, perhaps the entire cost of operating a plant for the production of fertilizer.

Ammonia is usually the most valuable fertilizing ingredient, amounting to 10 lbs. per capita per annum, worth, according to F. N. Taylor, $1.62.

Tidy, quoted by Rideal in his "Sewage," 1901, estimates the value of the components of 1,000 long tons of London crude sludge as shown in Table LXXIX.

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*Sewage Sludge, Elsner, Spillner, Allen–p. 83.

TABLE LXXIX

COMPOSITION OF SLUDGE FROM LONDON SEWAGE

	Pounds	Price per Pound
Ammonia	219.37	14.2c.
Phosphoric acid:		
Soluble	27.61	8.1
Insoluble	24.20	4.0
Potash	50.65	6.1

Resulting in a total value of 3½ cents per ton.

Professor Robinson, also quoted by Rideal, estimates the value of air-dried English sludge as shown in Table LXXX.

TABLE LXXX

VALUE OF AIR-DRIED ENGLISH SLUDGE

	Moisture	Phosphate of Lime	Nitrogen	Value per Ton
Aylesbury 1879	12.60	4.61	1.60	$6.27
Birmingham 1879	13.16	1.57	0.49	2.48
Bolton 1879	14.34	1.35	0.61	2.90
Bradford 1879	6.92	1.59	0.66	3.33
Coventry 1879	10.04	4.52	1.27	5.90
Leeds 1876	9.56	1.39	0.66	3.08
Leicester 1879	11.93	2.64	1.08	4.68
Windsor 1877	11.76	1.90	0.52	2.48

In 1907 the Royal Agricultural Society of England carried out an extended series of trials with seven different kinds of partly dried sewage sludge supplied them by the Royal Commission on Sewage Disposal. These experiments were continued for two years. One kind of sludge was compared with another in growing wheat and these were compared with artificial equivalents in the shape of fertilizers. As a result of the two years' work, substantially the following conclusions were reached, as stated by Voelcker in the Fifth Report of the Royal Commission on Sewage Disposal:

1. The sludges when used so as to supply 40 lbs. of nitrogen per acre increased the grain and straw of wheat 10 to 12 per cent. above unmanured produce.
2. The increase will be 5 or 6 per cent. less than the increase obtained with artificial equivalents supplying the same constituents in equal amounts.
3. Practically all the benefit is imparted to the first crop and little is left for a second.
4. The best sludges were moist and contained much lime.
5. The nitrogenous organic matter is not the determining factor in the value of sewage sludge: It is in an inert condition which requires lime to bring it into action.

6. Two dollars and a half per ton is an outside figure for the value on the farm of the sludges used (moisture 1.55 to 38.5 per cent.; nitrogen 0.53 to 2.24 per cent. and lime 3.87 to 26.67 per cent.).

At Hanover and Harburg partially air-dried sludge brings 24 cents for a two-horse load or 12 cents per cubic yard and at Unna septic sludge brings 36 cents per load. Apparently the demand is not sufficient to take all that is produced.

Probably the best form in which to prepare sludge as a fertilizer is by drying and grinding as practiced at Glasgow, Bradford and Kingston.

At Glasgow, Globe Fertilizer sells for $1.95 to $2.40 per ton in bulk or $3.40 in bags, but the demand does not equal the supply.

According to the manufacturer of the dryer used at Bradford, the price of the dried product is $2.17 per ton of material dried to 10 per cent. moisture, whereas formerly it cost $1.21 per ton to dispose of the cake. This cost was equivalent to $1.62 per ton of material with 10 per cent. moisture, making the saving on 38.4 tons at $3.79 = $145.54 per day. Deducting $12.94 for labor and fuel, the net profit from drying appears to be $132.60 per day or $48,000 per annum. Table LXXXI gives two analyses of the dried sludge.

TABLE LXXXI

Composition of the Dried Sludge at Bradford

	I Per Cent.		II Per Cent.
Moisture	10.00	Nitrogen	2.61
Ammonia	2.61	Phosphoric acid	0.11
Phosphoric acid	.31	Potash	0.31
Equivalent of bone phosphate	.66		
Potash	.24		
Grease	14.50		
Non-fertilizing material	71.68		
	100.00		

The valuations based on these analyses were $6.76 and $10.79 per ton, respectively. The cost of preparation is roughly estimated as shown in Table LXXXII.

TABLE LXXXII

Cost of Preparing the Fertilizer at Bradford

Pressing	$0.80
Drying	.40
Grinding	.15
Bagging	.15
Depreciation, etc	.10
	$1.60 per ton

The freight on the material to America is $3.50 per ton, where it is said to sell for $5.50 per ton.

At *Boston* a sludge has been obtained containing about 23 per cent. grease when dried to 5 per cent. moisture. The ammonia amounts to about 3 per cent. By extracting the grease with naphtha the ammonia content is raised to about 5 per cent., producing a fertilizer of value. A sample containing 5.26 per cent. was analyzed at the Massachusetts Agricultural College and appraised at $16 per ton.

At *Norwich, England*, a trial is being made with the "Echlenberg" process by which the wet sludge is blown through a 3-inch pipe located in the center of a 5-inch pipe. The sludge, introduced into the opposite end of the larger pipe flows toward the steam supply and is drawn through the smaller pipe with the steam and is in this way heated nearly to the boiling point. It is then readily pressed to 50 per cent. moisture and dried in a Ruggles-Coles dryer, the product being sold at about $3.80 per ton.

In some situations there is sufficient local demand to dispose of sludge cake to farmers without cost and perhaps with a little return. This is the case at Glasgow and Bradford. Elsner states that in England 18 cents per cubic yard is sometimes paid for its removal. At Halifax, England, about one-tenth of the cake is given away and the rest buried in the ground. At Bradford, the cake sells for 74 cents a ton, rough ground cake for $1.41 and fine ground material for $2.28 a ton. At Spandau the cake brings but 5 cents a cubic yard. At Manchester, the humus from contact beds is dried on floors, ground and sold for $5.43 per ton.

At Bockenheim, pulverizing in a rotary drum at 212° Fahr. and drying to 5.15 per cent. moisture was tried, but the cost of fuel ($6.48) per ton of poudrette was greater than the value of the material itself.

In a general way it may be said that under favorable conditions as to transportation a sludge containing 50 per cent. moisture, whose dried material contains 3 per cent. of ammonia and less than 10 per cent. grease, might be further dried, ground and sold as a filler for fertilizer with some slight profit in the case of large works; but that no other than an occasional and uncertain offset to a part of the cost of operation can be looked for even under favorable circumstances from the sale of sludge in the form of crude cake or containing over 30 or 35 per cent. of moisture.

Mr. John D. Watson, of Birmingham, in an address published in the *Surveyor,* January 9, 1914, describes a process for the concentration of sewage sludge which has been experimented with at Dublin, Ireland, with the object of producing a fertilizer.

Brewery yeast is added to the sludge and the latter is heated, whereupon rapid fermentation occurs and the molecular condition of the mass is changed so that it readily parts with its excess water. The fermentation takes place in troughs 50 feet long by 4 feet wide, holding about 3,000 gallons each. The sludge is heated before being delivered to these troughs and is kept at a temperature of 90° Fahr. in them for 24 hours. After fermentation, the water is drawn off from below, the sludge being reduced to about one-quarter of its original volume. A compound of phosphate and potash is then added, weight for weight, and the mass is dried in a cylindrical, vertical casing containing a series of arms and platforms revolving upon a center shaft. The platforms have large perforations in the shape of sectors and the mixture, which is fed in at the top, gradually falls through the drier to an outlet at the bottom. Air at a temperature of about 450° Fahr. is blown in at the bottom and passes out at the top. The dried product falls into a disintegrator consisting of a revolving paddle which beats up the product into a powder which is finally blown out at one end of the machine by a draft of hot air.

Recovery of the Grease in Sludge

Grease, while one of the most objectionable ingredients of sludge when used as fertilizer, is one of the most valuable when in sufficient quantity to warrant its extraction. The amount of grease found in (German) sewage is estimated by Dr. Beckhold quoted by Rideal in his "Sewage" at 8 lbs. per capita each year. The same author states that grease varies in sludge from 3 per cent. to 27 per cent., reaching, in scum, 80 per cent. In the dried sludge of several German towns, it ranged from 10 per cent. to 20 per cent. The sludge from Emscher tanks contains from 3 per cent. to 7 per cent. in the case of Essen-N. W. and Bochum. Where produced in large quantities, as at slaughterhouses, restaurants, wool scouring works, etc., it would seem that the grease could profitably be recovered at the source and sold.

The works at *Bradford* furnish perhaps the best example of the recovery of grease. The sewage, which is about one-tenth wool-scouring liquor, contains 440 parts per million of grease. The sludge, which contains 7.43 per cent. grease, is first treated with sulphuric acid and then heated to about 212° Fahr. The grease is mostly pressed out with the hot press liquor. From the presses, it goes to separating vats where the water is drawn off from the bottom. Thence it passes to tanks where it is boiled with black oxide of manganese and sulphuric acid or other chemicals and then, after standing 24 hours, it is barreled or else pumped to a large storage vat. It is sold at from $35 to $50.50 per ton.

For the six months ending September 30, 1907, the total cost of operation of the disposal works, exclusive of the Chief Engineer's salary, interest and sinking fund, was $48,472, and the receipts for grease and fertilizer amounted to $57,067, leaving a net profit of $8,595, most of which may be credited to the sale of grease.

In Germany the extraction of grease was tried at *Cassel*, as stated by Elsner in

"Sewage Sludge," by disintegrating and drying the pressed cake, subjecting it to steam and then extracting the grease by benzine in an extractor holding 8½ cubic yards. The grease and sediment were then separated from the benzine by steam and the latter condensed and used over. The distilled grease averaged 15 per cent. of the dried material in the sludge, which originally contained 18 per cent.

The Cassel plant cost $47,600. Sixty-five cubic yards of new sludge produced 6½ cubic yards of dry sludge, 1,650 lbs. of crude grease and 990 lbs. of refined grease, realizing $48.20, aside from fertilizer and other products, which are valued at about $40 more. The refined grease is sold at 4.87 cents per pound. But in spite of the large return, the expenses were greater than the receipts. This was due to the first cost of the plant, the wages of the men required and, especially, to the large amount of fuel. After three years' operation the plant was abandoned.

From this trial at Cassel and a similar unsuccessful attempt at Frankfort, Elsner concludes that no profitable use can be made of benzine. It would be preferable, he thinks, to remove the grease mechanically from the sludge in a Kremer tank. When the grease is first removed in a Kremer tank, it contains 72 per cent. moisture and the dried material contains 45 per cent. grease. The product is placed in a perforated vessel for further drying and is then ready for the market.

Elsner further concludes that a plant for this purpose is only warranted for towns having at least 45,000 inhabitants, while Spillner holds out the hope of a possible profit only in those cases where the percentage of grease in the dried sludge is above 15 per cent.

Grease from the Kremer apparatus at Charlottenburg is treated with bisulphate of potassium, charcoal and common salt and then cooked with steam. The clarified fat rises and the residue is disposed of with the sludge from the plant.

If the recovery of grease is attempted, its extraction from the sewage should be as complete as practicable. In this way it may be possible to make the process remunerative by the use of certain precipitants when it would not be so with others. Sulphuric acid has been mentioned in this connection as promoting precipitation of the dissolved or emulsified fats and yet at Bradford there remains 14½ per cent. of grease in the fertilizer containing 10 per cent. moisture. The grease is a detriment to its use as a fertilizer as well as a direct loss of an otherwise valuable product.

Experiments which have been carried on at the Boston Drainage Works indicate that by the use of sulphur dioxide, the dissolved grease is "cracked" or coagulated and so made recoverable much more completely than in any other way. This treatment, moreover, renders the effluent practically odorless and sterile.

Aside from its intrinsic value, the removal of grease is desirable in those cases where sludge is to be pressed, where it is to be used as fertilizer, where it is to be dried and in those cases where the sewage is to be distributed by sprinklers. The benefits derived from its removal may properly be added to the return from the sale of grease in judging the economy of the entire treatment.

The Use of Sludge as Fuel

Sludge after being dried has a certain value as fuel, depending on its original character and treatment which it has received. The percentage of moisture which the sludge contains is an important element in determining its value. If this is much over 70, combustion is not practicable and the expense of artificial drying below 50 per cent. is not warranted unless for considerations relative to transportation or preparation in a marketable form.

The British thermal units developed by the burning of sludge from various cities are stated in Table LXXXIII.

TABLE LXXXIII

Heat Units Developed from Burning Sludge

SLUDGE FROM PLAIN PRECIPITATION			
Stuttgart	47%	moisture	8,035 British thermal units
Hanover	28%	ash	15,870 British thermal units
Hanover	18½%	ash	17,120 British thermal units
Experiments at			
Philadelphia	51.8%	moisture	3,768 British thermal units
Philadelphia	34.8%	volatile	
Experiments by			
Bredtschneider and Proskauer	20%	volatile	8,730 British thermal units
Bredtschneider and Proskauer	30%	combustible material	
SLUDGE FROM SEPTIC TREATMENT			
Stuttgart	40%	moisture	6,456 British thermal units
SLUDGE FROM LIGNITE PROCESS			
Potsdam	60%	moisture	5,950 British thermal units
Cöpenick	40%	moisture	8,630 British thermal units

Experiments on the combustion of sludge mixed with pea coal were made in Philadelphia with the results stated in Table LXXXIV, taken from the Report of the Sewage Testing Station, 1911. The coal contained 12,065 b. t. u.

TABLE LXXXIV

Results Attained on Burning Sludge and Coal

Sludge	Coarse Particles Removed	Complete Sample	Partly Digested	Partly Digested
British thermal units as burnt	1877	2165	1216	1360
Pounds per cubic yard, broken	1015	835	840	710
Percentage moisture	32.2	40.2	35.8	15.3
Percentage, dry residue, volatile	30	28.3	29.2	24.5
Pounds of coal burnt, per pound of:				
Wet Sludge	.83	.68	.75	.895
Dry residue	.817	.875	.86	.945
Volatile matter	.246	.25	.25	.233

At Worcester experiments were made in 1891 in which 45 tons of sludge, containing 46 per cent. water, were burned with three cords of wood at a total cost of $3 per ton of dry solids; the cost was chiefly due to the handling of the material. Sludge with 72 per cent. water was burned at the rate of .24 tons per hour with very little fuel.

Kinnicutt, Winslow and Pratt in the "Sewage Disposal" conclude that if sludge contains 60 per cent. or less moisture, it may be burned, and that even with 72 per cent. moisture, burning is possible if great care is exercised.

Sludge dried to 10 or 20 per cent. moisture can be briquetted and in this condition it can be transported readily as fuel. At Bradford a briquetting machine has recently been installed by which the sludge not sold as fertilizer may be treated in this way. The machine has a capacity of five long tons per hour and requires about 20 HP. to operate. No binder is required, possibly due to the fact that a considerable percentage of grease still remains in the dry sludge.

Sludge produced by the lignite process is well adapted to utilization as fuel. With the use of from 4 to 8 tons of lignite per million gallons of sewage, the pressed cake is combustible. The lignite process, therefore, while costly in operation has this possibility of a partial financial compensation beside producing a very clean effluent.

A moderate amount of coal may profitably be added to ordinary partially-dried sludge for use under boilers. This was tried at Bradford, using one part of coal with seven parts of pressed cake and with forced draught. It was estimated that $4,760 was saved in one year by this practice.

At Huddersfield the Fifth Report of the Royal Commission on Sewage Disposal states that one part of coke breeze was mixed with five parts of sludge cake and burned at a cost of 56 cents per ton. The cost follows:

Coke breeze	33½c.
Stokers	13c.
Mixers	9½c.

The process was found costly, but the sludge was finally disposed of. Its calorific value was certainly considerable and the clinker produced was a further asset.

At *Ealing* sludge was formerly first mixed with two volumes of refuse and then burned with four additional volumes of refuse. More recently the sludge pressed to 60 per cent. moisture has been mixed and burned with 1½ to 2 parts of refuse at a cost of from 36 to 40 cents. This cost is recovered by the sale of clinker, leaving a margin of steam for power according to Kinnicutt, Winslow and Pratt in their work on "Sewage Disposal."

At *Bury* from 67 to 78 tons of cake mixed with twice that amount of refuse daily was burned under boilers and furnished 38 HP. besides which the clinker was utilized. At Charlottenburg one part of sludge with 75 per cent. moisture mixed with three parts of refuse evaporated from 0.67 to 1.08 lbs. of water per pound of mixture when burned under boilers.

It would appear from the experience cited above that if no more profitable use can be made of partially dried sludge than depositing in dumps, as is frequently done, there will be a probable saving in burning it under boilers with coal. If a refuse destructor is accessible, then it may very well be mixed with the refuse and consumed. In exceptional cases, as where containing lignite which has been used as a precipitant or where the sewage contains much coal from mine wastes, the recovery of the calorific value will be yet more profitable. If the sludge contains much grease this should first be separated out, both for its own value and to improve the remaining sludge for use as fuel.

Production of Gas from Sludge

Gases Produced by Decomposition. When sludge is allowed to decompose in the absence of oxygen, as in a septic or Emscher tank, large quantities of inflammable gas are produced. The gas is a mixture of methane, nitrogen, carbon dioxide and various other ingredients. The composition varies greatly and the quantity of gas given off depends, in large measure, upon the temperature of the sludge.

It has been suggested that the gases be recovered and utilized but no works have as yet been built to carry out this idea. It would appear that its feasibility was most promising in the tropics.

According to Rideal, the chemical processes which take place in the septic tank are as follows:

1. An hydrolysis of complex albuminous bodies which takes place in two stages: (a) conversion to a soluble form, peptonization; (b) hydrolysis of the peptones into amino acids, leucin, tyrosin and aromatic bodies. This process involves no gas formation.
2. Splitting up the amino acids into fatty or aromatic acids, with the formation of ammonia or nitrogen or both together.
3. The acids formed by the split of the albumin molecules break down into still simpler acids. In this process hydrogen and methane are generated.
4. The hydrolysis of urea to carbon dioxide and ammonia, which unite to form ammonium carbonate.
5. The decomposition of cellulose into fatty acids and carbon dioxide with the evolution of hydrogen or methane.
6. The hydrolysis of starches, sugars and gums to butyric and lactic acids with the formation of carbon dioxide, hydrogen and water.

7. The decomposition of fats. This is practically nil under anaerobic conditions.

8. The formation under the influence of bacteria of hydrogen sulphide and mercaptans from the sulphur in the organic molecule.

Carbon dioxide results from the breaking down of organic acids and the decomposition of the cellulose and carbo-hydrates. It varies greatly in amount, ranging from practically 0 to over 50 per cent. of the total amount of gas, with an average percentage apparently of less than 20.

The methane is sometimes over 90 per cent. of the total amount of gas, the usual proportion being about 70 or 80 per cent. The quantity of sulphuretted hydrogen is very small; there is frequently a total absence of this offensive odor. There is usually a trace of oxygen present and a small amount, usually less than 1 per cent. of a gas which is absorbed by Cu_2 CH_2 and has frequently been taken for carbon monoxide. Blood spectrum and iodine pentoxide tests made by Jesse in a systematic examination of the gases produced by septic tanks in Illinois led to the opinion that this gas was not carbon monoxide. Its identity remains unknown. There appears to be little or no ammonia produced. A considerable amount of nitrogen is usually given off. The amount may be as great as 60 per cent. or more, but is usually between 5 and 30 per cent.

Table LXXXV, prepared from data collected by Jesse, gives a considerable number of analyses of gas from septic tanks and Emscher tanks. The results given are stated as percentages.

TABLE LXXXV

GASES FROM SEWAGE TANKS

Town	CO_2	O_2	Gas Absorbed by Cu_2Cl_2	CH_4	N_2	H_2S
Urbana (averages of 12 samples)	12.28	.13	.45	81.02	6.14	
Champaign (averages of 3 samples)	27.23	.06	.08	72.18	.45	
Highland Park:						
Tank A	12.18	.0	.32	79.77	7.72	
Tank B (averages of 4 samples)	13.93	.35	.11	84.20	.99	
Tank C (averages of 2 samples)	20.3	.0	.0	73.96	5.73	
Chicago:						
Tank A, open septic	8.60	.0	.30	84.92	6.18	
Tank B, closed septic (averages of 2 samples)	6.08	.16	.34	83.6	9.7	.06
Tank C	9.31	.62	.45	83.9	5.72	
Dortmund Tank	6.42	.30	.0	60.	33.06	.22
Winnetka (averages of 3 samples)	9.35	.0	.44	87.12	3.09	
Lake Forest (averages of 2 samples)	8.5	.24	.65	87.78	2.76	
Woodstock (averages of 3 samples)	15.14	.08	.58	81.79	2.41	
Downers Grove (averages of 3 samples)	19.83	.04	.41	79.72	.003	
LaGrange	7.31	.0	.37	80.81	11.51	
Naperville (averages of 3 samples)	15.43	.24	.41	76.56	7.37	
Wheaton	9.33	.0	.72	82.10	7.85	.04
DeKalb (averages of 4 samples)	28.45	.04	.70	70.41	.40	
Collinsville:						
Tank I (averages, samples)	16.53	.22	.38	80.27	2.37	.20
Tank II	9.46	.09	.65	86.00	3.80	
Edwardsville	11.33	.15	.21	87.34	.97	

The decomposition of sludge at the bottom of rivers produces gases which do not differ materially from those which are produced by the putrefaction of sludge in tanks.

Following are the results of analyses of gases collected from the New York harbor and examined for the Metropolitan Sewerage Commission.

TABLE LXXXVI

GASES COLLECTED FROM THE HEAVILY POLLUTED PARTS OF NEW YORK HARBOR AND EXAMINED

	August 11, 1911			
	CO_2	O_2	CH_4	N_2
109th Street Dock, East River (averages of 3 samples)	5.2	0.1	89.8	4.6
	October 31, 1911			
East 109th Street, Harlem	7.6	0.2	85.4	6.8
East of Degraw Street	1.8	2.4	82.1	13.7
East 24th Street	2.4	1.3	83.3	13.0
Wallabout canal	4.2	0.4	86.7	8.7
Foot Broadway, Astoria	11.5	0.4	84.8	3.3

Recovery for Utilization. Besides grease, sludge yields appreciable volumes of other materials in the gaseous form on distillation. In 1910 the Massachusetts State Board of Health published the components found on the destructive distillation of 400 grams of different kinds of dried sludge as stated in Table LXXXVII.

TABLE LXXXVII

GAS PRODUCED FROM THE DESTRUCTIVE DISTILLATION OF SLUDGE

Source	Cubic Feet Gas, per Ton of Sample	Per Cent.						
		CO_2	Illuminant	O	CO	H	CH_4	N
Lawrence sludge*	4,900	4.4	2.2	0.3	30.7	34.9	18.6	9.1
Andover sludge*	6,400	7.4	15.1	0.6	14.3	22.9	34.3	5.4
Clinton sludge*	9,100	8.3	6.7	0.0	20.4	33.2	24.5	7.0
Brockton sludge*	6,000	16.5	21.4	0.2	10.3	22.6	29.1	0.2
Worcester sludge†	8,100	14.2	4.9	0.3	29.8	32.6	16.2	2.2
Septic tank sludge	4,900	7.5	1.9	0.1	24.3	44.0	13.0	10.2
Trickling filter sludge	6,000	20.2	17.4	0.3	6.6	32.7	22.8	0.0
Illuminating gas		3.4	9.1	0.0	21.5	42.5	19.7	3.8

*Plain settled.
†Chemically precipitated.

The calorific value of sludge depends to a large extent on the moisture contained in it; the moisture has to be evaporated before the more valuable constituents can be recovered.

Elsner in "Sewage Sludge" gives the calorific value of the dried material of sludge as about 7,200 b.t.u. per pound and then proceeds to show how many heat units must be absorbed in the distillation of sewages with different degrees of moisture before the 7,200 units can be realized. His figures are contained in Table LXXXVIII.

TABLE LXXXVIII

Heat Units Absorbed in Converting the Moisture of Sludge to Steam

Per Cent. Moisture	British Thermal Units to Convert to Steam	Per Cent. Moisture	British Thermal Units to Convert to Steam
10	126.7	60	1,728.0
20	288.0	70	2,684.2
34	495.4	80	4,608.0
40	771.8	90	4,608.0
50	1,152.0		

From this Spillner concludes that unless it is first reduced to 80 per cent. moisture, sludge has no practical calorific value and that if it is dried artificially, there will be little gain in carrying this reduction beyond 50 or 60 per cent. moisture.

Experiments have been made at Oberschöneweide in which 5.63 to 8.23 tons of lignite with 0.75 to 1.13 tons of sulphate of alumina were used per million gallons of sewage. It furnished 12.5 tons of sludge 64 per cent. moisture with a calorific value of 3,202 b.t.u. This was air-dried to 51 per cent. moisture for it was shown that when the sludge contained as much as 58 per cent. moisture, conversion to gas was not practicable. The results were as shown in Table LXXXIX.

TABLE LXXXIX

Gases in Sludge Treated with Chemicals

Carbon	22.3%	Oxygen	12.8%
Hydrogen	2.7	Sulphur	0.5
Nitrogen	1.0	Ash	9.8

The calorific value per 1,000 cu. ft. of the gas was 81,000 b.t.u. By the use of this gas in a gas engine the cost of operation of the clarification plant was reduced from 33.1 to 24.5 cents per capita per annum or by $16.20 per million gallons of sewage, including fixed charges.

In general it may be said that little has been done in the way of utilizing the gas from sludge either for illumination or power. The Massachusetts experiments showed a great variation in the composition of sludge of different towns. The sludge from Andover, Brockton and trickling filters was high in value as an illuminant, while that from Lawrence, Worcester and septic tanks was low.

It is probable that although the digested sludge is not valuable for gas production, the gas evolved from septic or Emscher tanks might in large installations be utilized for either light or power in the neighborhood of the plant.

Experiments in the distillation of gas for power from sludge have been mostly confined to Germany and the results obtained have not given promise of any great pecuniary benefit to be derived unless under such special conditions, as when the sludge contains coal dust, lignite or other material of high calorific value.

FINANCIAL RESULTS

A general review of the attempts that have thus far been made to utilize sludge do not encourage the belief that any great profit can be derived, except in cases where the nitrogen or fats are abnormally high. Under other conditions, past attempts to secure anything more than a nominal revenue have, as a rule, resulted in failure. The crux of the problem is the separation of the water and the concentration of the valuable ingredients. This is necessarily costly, whether done mechanically or by the direct action of heat.

The cost of pressing sludge so that its moisture is reduced from 95 per cent. to 55 per cent. is shown in Table XC.

TABLE XC

COST OF PRESSING SLUDGE

Large Towns		Small Towns	
Per Ton Wet Sludge	Per Ton Pressed Cake	Per Ton Wet Sludge	Per Ton Pressed Cake
$0.10	$0.50	$0.23	$1.00

The cost of drying from 90 per cent. to 60 per cent. by centrifugal machines amounts to about 10 cents per cubic yard of wet sludge or 45 cents per cubic yard of product.

The further drying from 60 per cent. to 10 per cent. moisture by rotary dryers may cost 75 cents per ton of dried material.

The revenue to be derived from the sale of dried sludge as fertilizer and from grease will, in many cases, more than offset the cost of production, in large towns, besides furnishing a sanitary and inoffensive method of disposing of sludge.

The drying of sludge for fertilizer and the extraction of the contained grease offer a more promising outlook than others. In many works where it would not be worth while to undertake these somewhat elaborate processes, it will be found of advantage to dispose of the semi-dried centrifuged or pressed sludge to farmers for what it will bring or else burn it under the boilers of the plant.

CHAPTER II

PRINCIPLES OF MAIN DRAINAGE AND SEWAGE DISPOSAL APPLICABLE TO NEW YORK, WITH EXAMPLES DRAWN FROM VARIOUS LARGE CITIES

MAIN DRAINAGE

By main drainage is meant an arterial sewerage system whose function it is to collect the sewage of one or more local sewerage systems and carry it to one or more central points for final disposition.

Main drainage is contrasted with local drainage chiefly in its ultimate object. Whereas the purpose of main drainage is to protect the rivers, lakes and harbors upon which cities are situated, the object of local drainage is to remove the sewage of the houses and streets from its immediate points of origin. Local sewers, as ordinarily built, may pollute the natural waterways. With main drainage these natural bodies of water can be kept reasonably clean.

The sewage which is collected by a main drainage system must, of necessity, be discharged somewhere, and to prevent excessive pollution at the point of outfall, it is often desirable and usually feasible to pass the sewage through some process of purification before the final discharge takes place. The method of disposal which it is best to employ, like the system of main drainage which is tributary to it, depends upon various conditions, including the quantity of sewage and the facilities which exist for the discharge of the effluent.

Some of the engineering principles upon which a system of main drainage is constructed are, in many respects, the same as those upon which local sewerage systems are based. In each case the sewage generally flows in closed conduits which are built large enough to accommodate the greatest flow of sewage which is expected. The currents are maintained by gravity and the gradients upon which the sewers are laid are such as are intended to insure rates of flow sufficiently rapid to prevent deposits taking place. In many instances catch-basins, screens and other forms of apparatus are provided, in order to permit the removal of solid matters which would interfere with the flow of the sewage or with the operation of pumps. Other appurtenances commonly employed are pumps to raise the sewage, regulators to deliver into the main drainage system that part of the sewage which it is intended to carry and divert the excess to storm overflows, and tide-gates, whose duty it is to exclude tidal water.

Practically all main drainage works operate in connection with local sewerage systems built upon the combined plan. The collection of house sewage and storm water in separate systems of conduits is practiced in very few large cities.

Terms and Assumptions Used by the Commission

In the studies of the Commission various terms have been employed to describe the types of sewers used in the main drainage works, and the meaning which has been attached to these terms has been always the same. Sewers running parallel to the shore line and intended to intercept the flow of sewage from the local sewers have been termed *interceptors.* Sewers which have penetrated for a considerable distance inland to collect the sewage from a territory not adjacent to the harbor have been called *collectors.* Sewers extending from pumping stations to more or less distant points and intended to carry the sewage from one place to another without receiving additions on the way have been called *mains,* whether operated under pressure or by gravity. *Siphons* are deep-lying sewers usually extending under some part of the harbor and intended to carry the sewage under an obstacle. *Marginal sewers* are relatively short interceptors near the waterfront connected with larger near-lying interceptors in the same territory. No distinction has been made between sewers built as tunnels and in open cut, the method of excavation being of no importance in the final works.

The term *district* has been restricted by the Commission to the metropolitan sewerage district of New York and New Jersey, which is the territory laid out by the Commission in 1908 for the purpose of its studies. A description of the metropolitan district, its distinctive topographical characteristics, population, industries and the increasing pollution of its waters were described in the report of the Commission, April 30, 1910, Part II, Chapter I, page 51 and following.

The term *division* has been used by the Commission to indicate one of the four principal parts into which the City of New York was separated in these studies for the purpose of working out the general principles of main drainage and sewage disposal which were most applicable to the situation. A *subdivision* was a smaller part into which a main division was separated. The divisions have been known by the waters to which their drainage areas were naturally tributary. The subdivision was described by its location, by the name of some well-known locality or, where the subdivisions were very numerous, by a number, the location of which could easily be ascertained.

Drainage area has meant natural drainage area and not the territory which, by pumping or other means, could be made tributary to a single sewer outlet or group of outlets.

Sewage has included the drainage of houses, streets and industrial establishments, such as contribute to the flow of sewage in the combined sewers of New York City. Where the drainage of houses has alone been considered, the term *domestic sewage* or *house sewage* has generally been employed. The term sanitary sewers or sanitary sewage has never been employed in the reports of the Commission.

The evidences of pollution, whether recognizable to the senses or detectable by analyses have rarely been referred to in the Commission's reports as sewage. *Sewage matter* or *sewage materials* or *organic matter* have generally been employed to indicate the contaminating substances, whether solid or liquid.

In referring to methods of disposal, the term *purification* has been used sparingly to indicate practically all methods by which sewage may be more or less completely relieved of its harmful and offensive properties. The production of an absolutely pure effluent has not been thought to be necessary in employing this term. *Sewage treatment* is a synonym of purification, the difference in meaning being slight and relatively unimportant, so far as the Commission's reports have been concerned. By *submerged outlets* the Commission has meant pipes or other structures intended to discharge sewage at the bottom of the harbor. *Surface water* is water near the top in the harbor and not the actual surface.

Local sewers are often built by cities in a piecemeal manner and with little or no consideration for the need of co-ordinating the various outlets. In a city such as New York, with several hundred outlets, it may be said that several hundred local sewerage systems exist.

In course of time the independent outlets require to be wholly or partly eliminated and the unrelated sewerage systems made tributary to a comprehensive main drainage system. Where careful scientific design forms the basis of the main drainage works, the sewage will not only be carried away to the best advantage, but a sanitary disposition will be accomplished at a minimum of cost, obsolete methods will be avoided and haphazard work will be prevented.

The quantities of sewage to be provided for in the plans which the Commission has made for the main drainage of New York have been based upon estimates of populations and allowance of per capita production of sewage per 24 hours.

The population has been the subject of long-continued study. A discussion of this subject will be found in the report of the Commission of April, 1910, Part III, Chapter II, page 133 and following. Where the most accurate estimates practicable have been necessary for certain areas, the Commission has proceeded as follows: The latest census returns have been plotted upon a map, using the smallest political divisions included in the census as the boundaries within which the data were included. Dots made with inks of different colors were used to represent units of 500, 1,000 and 5,000 of the population, the distribution of the dots within the area being based upon personal judgment resting upon familiarity with the neighborhood. The number and color of the dots thus found to be contained within a drainage area have been taken to indicate the number of persons whose sewage was tributary to the sewers whose flow was to be estimated. Allowance was made for transitory population in those parts of the city wherein this factor seemed likely to play a considerable part.

The per capita allowance of sewage derived from the public water supply was based largely upon information obtained from the authorities in charge of the public water supply. The average production per capita per day for the several boroughs has been taken at 160 gallons for Manhattan and 125 gallons for the other boroughs. It has been assumed that one-half the total quantity of domestic sewage would flow off in eight hours, which is equivalent to a maximum rate of 50 per cent. in excess of the average rate. The maximum rates then are 240 gallons for Manhattan and 187.5 gallons for Brooklyn, Bronx, Queens and Richmond.

The trade wastes were allowed for in the per capita volume of domestic sewage on the assumption that the volume of water becoming trade wastes over and above that secured from the water supply would be balanced by the loss of water from the water supply which did not reach the sewers.

From measurements made on maps of the Boroughs of Manhattan, The Bronx, Brooklyn and Queens, it was found that there were on an average from about 26 to 28.5 miles of streets measured on the center lines per square mile of area of built-up district. With each street sewered and making a deduction for length of sewers not carried across intersections, it was considered reasonable to assume the length of sewers to be 25 miles per square mile in built-up districts and 15 miles in suburban districts.

The leakage into the sewers was assumed at a maximum of 30,000 and an average of 15,000 gallons per mile of sewers per 24 hours.

Combining these leakages with the lengths of sewers the following assumptions for the leakage per square mile of area were arrived at.

Character of district	Miles of sewers per square mile of area	Leakage into sewers Gal. per square mile per 24 hours	
		Maximum	Average
Built-up	25	750,000	375,000
Suburban	15	450,000	225,000

Sewers over 2 feet in diameter were designed to carry the maximum rate of sewage flow when running three-quarters full (not three-quarters full depth). Sewers 2 feet in diameter and less were designed to carry the maximum rate of sewage flow when running one-half full capacity.

The coefficient of roughness in Kutter's formula was taken at $N = 0.013$ for pipe sewers and 0.015 for concrete and brick sewers.

The minimum velocities provided for in the design of the main drainage system are calculated as for circular sewers and are believed to be approximately correct for ordinary cross-sections. If $Q =$ the maximum volume of discharge per second, the minimum velocity was 1.9 feet per second when the volume of discharge was $\frac{1}{3}$ Q and the depth of flow, in terms of the diameter, was 0.34. The minimum velocity was 2.25 when flowing at the rate of $\frac{2}{3}$ Q or $\frac{3}{4}$ Q.

STORM WATER

It is not customary for cities to build works to treat all their storm water. The volume is so great, even when moderate falls of rain occur, that the works required to purify all the storm water would be excessively large and costly. There is, moreover, a general belief that the waste water from the roofs of houses and from the streets does not contain enough putrescible material to add materially to the pollution.

The literature relating to the treatment of storm water shows that experts generally consider that storm water from closely built-up cities is capable of producing at least as much offense as house sewage. There is reason for believing that the first flush of storm water is worse than even the relatively concentrated sewage of European cities, and that it is therefore desirable to treat a portion of the storm water.

European and American Sewage.—Much of the recorded information and opinion which exist with respect to the polluting effects of storm water is based upon European conditions, where the quantity of sewage at times of dry weather may amount to 20 or 30 gallons per capita per 24 hours. If the quantity of sewage in American cities is taken at 120 to 180 gallons per capita, it is evident that the argument for treating storm water has more weight in America than it has abroad, for if storm water is as bad as domestic sewage when the latter is concentrated to the extent of 20 or 30 gallons per capita per day, it must be about six times as bad when the domestic sewage is so dilute.

The aggregate weight of solid matter carried by storm water is very great. Analyses can be quoted which show that the percentage of suspended matter is several times as high in sewage containing storm water as it is in purely house sewage. This being so, and it being remembered that the volume of sewage is greatly increased at times of storm, it follows that the total amount of suspended matter carried by a given volume of storm water is much greater than the analyses indicate.

Numerous experts have expressed the opinion that careful attention should be given to the polluted character of the first flush of storm sewage. In the opinion of Samuel Rideal, whose familiarity with the chemical and biological composition of sewage and whose knowledge of current practice in England entitles him to be regarded as an authority, "whatever system be adopted, the raw storm water of populous districts should never be allowed to pass in large volumes at the beginning of a storm directly into a stream." Dr. Dunbar, Director of the Hygienic Institute at Hamburg, and an authority on sewage disposal on the Continent of Europe, as well as in England, says: "It must not be supposed that the contents of rain water sewers are in general not so polluted as ordinary sewage. In busy districts, the washings from the streets, even if these are thoroughly cleaned daily, are everywhere found to be worse in every respect, including putrescibility, than ordinary sewage." Dr. Houston, the celebrated English bacteriologist, says that storm water is as "potentially dangerous to health as normal crude sewage." To these opinions many more could be added to the same effect.

American Analyses.—There is scant information on record to show the composition of storm water in American cities, although some data are available to indicate the average composition of sewage containing the combined drainage of houses and streets. This information is not as valuable as it would be if it had been collected with the intention of showing the difference in composition which occurs in the sewage of a given city during dry weather and at periods of storm, but some facts exist with respect to this subject.

At a testing station, established at Gloversville, N. Y., at which analyses were made continuously for about one year, 1908-1909, the marked effect of storm water upon the dry-weather flow was shown in the following manner. Following a period of dry weather, rain fell for practically 24 hours on June 5th and the flow of sewage increased 31 per cent., although comparatively few storm water drains were connected with the sewers. The storm water came chiefly from the roofs of houses and from the streets. The strength of the sewage increased as follows:*

Total suspended solids from 312 to 622 parts per million, or 166 per cent.

Volatile suspended matter from 196 to 254 parts per million, or 73 per cent.

Fixed suspended solids from 116 to 368 parts per million, or 324 per cent.

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* Report to the City of Gloversville, N. Y., by Eddy and Vrooman, Aug. 7, 1909, p. 57.

It is worth noting that the largest increase in suspended matter was due to non-volatile, fixed or mineral matter. This suggests that storm water is peculiarly susceptible of improvement by settlement, an inference which is not strictly correct, for the removal of mineral matter would not produce nearly as much benefit as the removal or organic or nitrogenous matter. A large part of the suspended matter is grit.

The average composition of the combined sewage of some American cities, as determined by numerous analyses made at investigating laboratories, is indicated in Table XCI.

TABLE XCI

Composition of Sewage at Various Testing Stations.

(Parts per Million)

	Suspended Solids.				Nitrogen as			Oxygen Consumed.			Cl.	Fat.
	Total.	Fixed.	Volatile.	Organic.	Free Am.	Nitrite.	Nitrate.	Total.	Sus.	Dis.		
1. Boston, 1903–5	......	......	......	......	18.5	.19	.10	43.1	19.3	23.8	....	....
2. Boston, 1905–7	135	44	91	9.1	13.9	.00	.20	56.0	13.0	43.0	....	....
3. Columbus, 1904–5	209	130	79	9.0	11.0	.09	.20	51.0	25.0	26.0	65	25
4. Waterbury, 1905–6	165	50	115	14.8	7.8	.14	1.52	46.0	20.0	26.0	48	26
5. Gloversville, 1908–9	406	177	229	23.0	12.0	.38	.87	95.0	50.0	45.0	158	48
6. Philadelphia, 1909–10	189	59	130	6.3	4.0	.23	1.00	76.0	....	40.4	39	28

In each of the investigations whose results are indicated in the foregoing table, an effort was made to obtain results which would be helpful in the design of works for the purification of the sewage. Certain peculiarities were thought to exist in the sewage to be dealt with which it was necessary to determine and the amenability of the sewage to purification was tested in each case.

It will be observed that the sewages tested at the experiment stations varied considerably in the amount and nature of the suspended matter, as well as in the dissolved impurities. If partial treatment only had been thought sufficient, it would not have been necessary to make the analyses so complete. So far as the general character of the average sewage dealt with is concerned, the figures given are satisfactory, but they should be employed with caution in forming an opinion as to the composition of the sewage of other cities where importance attaches to questions of detail.

Opinion With Respect to Manhattan and Brooklyn.—Should the house and storm sewage of Manhattan be collected in separate systems, it would be desirable certainly to treat all of the one and perhaps part of the other. This could not conveniently be done in the same plants. Should both house and storm sewage be collected by the combined system, the treatment works should be so designed as to deal with the dry-weather flow and have enough more capacity to take care of the heavily polluted water which would be washed from the streets and houses with the first flush of the rain. It would be well to have the capacity of the main sewers and disposal works equal to twice the average dry-weather flow.

SEWAGE DISPOSAL

The method of final disposition which it is best to employ in any case depends largely upon the facilities which are available for discharging the sewage after treatment into the natural body of water which must receive it.

If the volume of sewage is relatively small as compared with the quantity of water into which it can be discharged and the point of outfall is so situated as to be removed from localities where there is likely to be offense, a minimum degree of treatment is all that is required. On the other hand, if the diluting capacity of the natural body of water is small and the point of outfall so situated that the discharge of the sewage may produce a nuisance, a more thorough removal of the offensive ingredients is called for. Every situation requires independent study. There are no rules which it is safe to lay down for universal application. What is permissible with one group of conditions may prove to be entirely unsatisfactory with another.

Considerable misapprehension exists on the part of the public concerning the possibilities of sewage purification, it being believed by many persons that the manurial ingredients constitute a rich source of profit and by many others that it is within the range of practicability to so deal with sewage in disposal plants that the effluent shall be incapable of producing nuisance and be harmless from the standpoint of disease. Theoretically, such thorough purification can be effected, but practically it is rarely, if ever, accomplished. Only in rare instances is it necessary or possible to attempt such thorough treatment. The cost of completely ridding sewage of its nuisance or disease-producing capacity and the nuisance which is likely to be produced in the vicinity of such works make it desirable to seek some other solution of the sewage problem. It may be better to collect the sewage to some other central point or discharge the effluent into some other natural body of water or to modify the standard of purity required for the effluent.

Among the methods of disposal most often employed is the discharge of the crude sewage into a river, lake or harbor under circumstances which seem likely to carry it promptly away. This has been termed the method of dilution, but, as practiced by most cities, disposal in this manner is less a method than a means of escaping the methodical disposition of the sewage.

In disposal through dilution, the sewage is ordinarily carried by a local or main drainage system to one or more points and discharged where the prevailing currents will carry it away. Where the discharge can be made into rivers, especially those whose waters are muddy and of ample volume, and where the chances of nuisance or injury to health to other communities further down-stream may be neglected, this way of getting rid of the sewage has much to recommend it. It is the cheapest plan that can be followed. Where the diluting power of the natural body of water is insufficient, where the currents oscillate, as, for example, in tidal harbors or where water supplies are likely to be injuriously affected, disposal by dilution is less applicable.

Engineers who have studied the subject have arrived at the opinion that so far as nuisance is concerned, disposal through dilution is likely to prove satisfactory in inland rivers where the quantity of water flowing is equal to, or greater than, about 3½ cubic feet per second per thousand of population supplying the sewage. See this report, Part III, Chapter II, Section IV, page 335, and Part IV, Chapter VI, page 633. For reasons which are explained elsewhere, it is impossible to calculate the dilution which the sewage of New York receives when discharged into New York harbor. See this report, Part IV, Chapter III, page 493.

Where the dilution is insufficient to dispose of crude sewage satisfactorily, some form of treatment which will remove sufficient of the impurities to permit the remainder to be discharged is usually resorted to. The design of the disposal works depends upon the degree of purification required and the opportunities which are available, such as area of land, hydraulic head at which the sewage may be obtained, location of the works with respect to the congestion of resident or business population in the vicinity and the facility with which the impurities which are removed can be disposed of. The best design of works will take into consideration all of these factors as they relate to the particular situation under consideration and have due regard to the need of keeping the cost of construction and maintenance down to the lowest terms.

The methods which are available for the purification of sewage may be divided into two large classes: Those which contain processes for the mechanical removal of the impurities and those in which oxidizing processes are employed.

No single process is in itself complete. Even the simplest methods of sewage disposal which are likely to be employed in any city require the combination of two or more distinctly different steps.

MECHANICAL PROCESSES

1. *Fine Screens*

Screens designed primarily for the removal of the small particles of suspended matter in sewage as distinguished from rags, sticks, straw, orange skins, etc., are generally known as "fine" screens and have free spaces between the bars or wires of 15 mm. (0.6 inch) or less.

They may be classified as consisting of bars, links, a wire mesh or a perforated plate; as fixed or movable; according to the general design. There are, in particular, three prominent types of fine screens, all of them of German origin, viz.: the Hamburg, the Frankfort and the Dresden types.

These are all in successful and satisfactory operation in a number of German cities. They are usually operated by electric motors and are cleaned above the surface of the sewage.

The Hamburg Screen. The Hamburg screen consists of a band composed of aluminum links 0.2 in. thick, 14.4 in. long and spaced 15 mm. (0.6 in.) apart. There are two screens, side by side, at the lower end of the grit chamber, each 11½ ft. wide. They pass in an inclined position over two rollers, one above and the other below the sewage. The entire length from out to out is 32.8 ft.

As the upper links rise slowly from the surface they carry the material which has collected over the top roller. Behind the screen, near the top, there is a rake of hard rubber which, by mechanism, engages between each set of links, scraping off the detritus, which is then scraped from the rake on its withdrawal on to a lateral belt conveyor. The velocity of the screen is about 0.2 or 0.24 in. per second.

To operate the screen and the cleaning device about 5 H. P. is required.

The Frankfort Screen. At Frankfort-on-the-Main there are three screens in form like paddle-wheels. Each is composed of five blades or wings extending 9.8 feet from the axis and 6.6 feet wide. The wings themselves are made up of straight parallel bars placed radially to the axis and spaced 10 mm. (0.4-in.) apart. In operation the lower wings move against the current, intercepting the detritus which is unable to pass beyond, as one wing of the screen always occupies the cross-section of the stream.

As the wing rises, a straight scraper of rubber, hung at each end by a long arm from above the center of the screen, is forced from near the axle to the outer edge, carrying with it the screenings, which drop on a horizontal plate. On the horizontal motion of this plate the screenings are scraped off to a lateral belt conveyor and transported for disposal. After reaching the edge of the wing the scraper drops to the inner part of the following wing and the operation is repeated.

The sewage passes a coarse screen with 155 mm. (6.1-in.) spaces between the round bars and then a grit chamber before reaching the fine screens. Of the suspended solids in the raw sewage 16% are removed by the grit chamber and 10% more by the screens (Koelle). Other analyses made several years ago gave the following average results:

	Suspended Matter Parts per Million.		Per Cent. Removal.	
	Total.	Organic.	Total.	Organic.
Raw sewage	411	241	...	...
Effluent from fine screens	325	185	20.9	23.2

The Dresden Screen. The Dresden, otherwise known as the Riensch-Wurl, screen consists of a circular bronze disc, 26.2 ft. in diameter, on the center of which is placed a conical plate of less diameter. These plates are perforated with slots 2x30 mm. (.08x1.20 in.) in size. The whole is mounted on a central shaft inclined 15° to the vertical around which it revolves once in about three minutes. Being partly submerged in a channel closely fitting the lower edge of the disc, the suspended material is gently raised above the surface and on reaching the highest point is brushed off the disc by cylindrical brushes on the ends of four revolving arms. The conical surface is cleaned by a single large cylindrical brush. The screenings fall to a conveyor by which they are removed from the vicinity of the screen.

The sewage first passes a grit chamber, then coarse screens with bars spaced 45 and 66 mm. (1.8 and 2.6 in.) apart, which remove about $^{1}/_{20}$ cu. yd. of paper, rags and other coarse material for each million gallons of sewage.

The fine screens remove 15 to 20 cu. yds. additional, containing 80% moisture. The following table gives the results of 22 tests made between Feb. 18 and May 4, 1913:

	Samples taken:	
	Before Screening.	After Screening.
Suspended solids, ppm*	5590	3520
Specific gravity	1.5537	1.5622
Per cent. moisture	95.8	95.1
Weight of dried material—		
In grams per litre	0.30512	0.23672
Mineral " "	0.11162	0.09280
Organic " "	0.18995	0.13673

*Parts per million.

About 2½ H. P. is consumed in operating one of these screens.

2. *Grit Chambers*

All sewage, and particularly the sewage from combined systems of sewers, contains grit and other relatively heavy particles. Attempts are often made to remove as much of this heavy matter as possible before the sewage passes entirely from the street gutters to the sewers. The devices customarily employed for this purpose are called catch-basins.

Theoretically desirable, catch-basins are, in reality, among the most useless devices employed for the removal of solid material from sewage. They are generally ineffective because they are not cleansed with sufficient frequency to enable them to serve as traps. It seems impracticable to keep them clean. To maintain catch-basins in serviceable condition requires much hand labor, and this is costly. The work is usually carried on to the annoyance of pedestrians and householders. Some sewerage systems are without catch-basins, and their elimination, as a general procedure, is much to be desired.

Where sewage from a combined system of sewers has to be pumped, it is customary to construct at the pumps coarse screens to remove large, light suspended solids, and grit chambers to collect sand particles and such heavy suspended matters as are capable of being quickly deposited when the sewage is brought to a state of comparative rest. Grit chambers are capable of being efficiently operated, for their size, location and form make them comparatively easy to clean. Mechanical dredging apparatus may be located above the grit chambers and so operated as to remove the accumulations as rapidly as they are deposited. The solids extracted are of little or no use. They are commonly removed in cars which run upon industrial railways and discharge their contents into barges or into railroad conveyances for ultimate dumping. The gritty material may produce offensive odors because the organic matters which cling to it are capable of putrefaction.

Grit chambers are of much practical service when used in connection with coarse and fine screens. The sewage first flows through the coarse screens, then through the grit chambers and finally through the fine screens. It is customary to build screens and grit chambers in duplicate so as to facilitate the work of cleaning and repairing.

Grit chambers and screens take up but little room. They can be constructed in the built-up parts of cities. No offensive odor need be produced by them. They are appropriately employed wherever the pumping of sewage is necessary, wherever much gritty matter is washed from the streets, and in those cases where the sewage is subsequently to be treated for the more complete removal of its impurities. In Germany, where much sewage is discharged into large, rapidly flowing, turbid rivers, fine screening is a standard procedure, except where a more complete removal of the suspended matters by sedimentation is adopted. Even in this case they are sometimes placed before the tanks to take out the floating material.

To remove the greater part of the grit with the least amount of organic matter the velocity of flow through the grit chamber should not vary greatly from one foot per second.

3. *Sedimentation Basins*

Sedimentation basins, wherein the sewage stands almost at rest for a period generally of two hours, more or less, generally take the form of large, shallow, open masonry reservoirs. The sewage enters at one end and flows out at the other, the desirable rate of passage being generally not over an inch per second. Compartments, baffles, wiers and other devices are sometimes employed in order to secure a uniform rate of flow. If left to itself in a large basin the sewage will flow in and out by the shortest route and will not circulate with that completeness necessary to afford the longest period possible for deposition. Special pains must be taken to compel the sewage to flow uniformly through the basin in order that all the solid particles shall have an equal opportunity to settle out.

In some cases sedimentation basins are constructed with hopper-shaped sumps in the bottom, facility in cleaning being thus obtained.

The ordinary sedimentation basin is cleaned by drawing off the sewage and sending laborers with rubber boots and squeegees to push the solid accumulations on the bottom to the outlet pipes. This cleaning is expensive and unsatisfactory from a sanitary standpoint. It is an exceedingly dirty operation. Tanks built with hopper bottoms require little or no hand labor in removing the sludge.

A type of settling basin which has recently received much favorable notice has a relatively small superficial area and great depth. The solid matters which are deposited can be drawn off from the bottom without emptying the tank of sewage. Several forms of this deep tank are in use. The oldest is known as the Dortmund tank.

The Dortmund tank resembles a cylinder or cube with a conical or pyramidal bottom. The most recent forms are somewhat complicated, but have advantages which appear to make them a distinct improvement over earlier types of settling basins.

The latest advance lies in providing the deep settling basins with traps or compartments at the bottom, into which the depositing solid matters settle and decompose. The gases of decomposition which rise from the deposits in the lower chamber escape through vents especially provided for them. The sewage does not decompose as it passes through the settling basin, nor become foul smelling, but remains almost as fresh and inodorous as it was when it arrived at the works. The deposited matter which ferments gives off large volumes of gas which are inoffensive. This settling basin, known as the Emscher tank, from the name of a small river valley in Germany, where it was first employed, is now being installed in many cities in Europe and America.

The period of settlement allowed for the deposit of the solid matters from the sewage is commonly four hours or more, but occasionaly it is less than two hours. The material which is deposited from the sewage and allowed to ferment in the separate chamber of the Emscher tank is reduced in volume by decomposition and so altered in physical constitution that it easily parts with its water when spread out upon a coarse draining bed.

When ordinary sewage is allowed to remain in a quiescent condition for eight hours or more, it undergoes a process of biological change which is essentially putrefaction. The oxygen which was present in dissolved form is consumed and anaerobic fermentation sets in. Sedimentation basins in which anaerobic action takes place throughout the volume of sewage are known as septic tanks. They are usually offensive by reason of the unpleasant odors which they give off. In order to reduce the nuisance from smell and to facilitate the biological actions which are desired, the tanks are sometimes covered.

At one time it was supposed that the putrefactive fermentation of sewage was highly desirable from the standpoint of purification. It was believed that the solid organic matters which the sewage contained could be completely converted into liquid and gaseous forms by the so-called septic action and that the greatest obstacle to the purification of sewage, namely, the disposition of the sludge, would in this way be done away with. Experience has failed to justify this expectation. Septic tanks are now regarded with less favor than formerly. It is not held to be desirable to putrefy sewage as a step toward complete purification. It seems better to keep it as fresh as practicable throughout the purifying process.

Septic tanks have usually been built in the form of large and comparatively shallow basins. They should not be located in a closely built-up city. The sewage which passes from them is often highly offensive. If the sewage is to be subjected to final treatment on sprinkling filters, the odors in the vicinity of the filters are likely to cause complaint. There are some situations in which septic tanks may be useful, as, for example, in small installations where the quantity of sludge must be reduced to a minimum and where odors are not seriously objectionable.

Sludge.—The disposition of the solid impurities which are removed from sewage in sedimentation basins constitutes the most serious problem usually confronting sewage engineers. This material, termed sludge, unless it is retained a long time in the basin so as to decompose, consists largely of colloidal matter. Its specific gravity is but slightly greater than that of the sewage from which it has been deposited. It consists largely of water, and this water can be extracted only with the greatest difficulty. Sludge will remain for months without perceptible change in physical, chemical or biological condition. It flows like water, a fact which has led engineers to say that pumping was the only thing which it was easy to do with sludge.

Sludge can be dried, although drying is usually a difficult and expensive process. The water can be extracted by filter presses. It can be removed in centrifugal machines. When dried, sludge can be burned.

The usual way of dealing with sludge is to dump it upon low-lying land. Cities situated upon the sea sometimes pump it into ships which carry it to the ocean and there discharge it overboard. Some cities bury it, others dig it into the soil, a few dry and burn it, and perhaps a dozen turn it into fertilizer.

If sludge is so managed as to permit it to ferment, it undergoes changes which alter its physical condition. In place of the amorphous, almost slimy consistency which it originally possessed, it becomes somewhat granular and porous. Placed upon a suitable under-drained piece of land, fermented sludge quickly drains itself of a large part of its water, so that in a few days it may be spaded. It is, moreover, without unpleasant odor. It is obvious that in fermentation there lies a good prospect of dealing with sewage sludge in an economical, sanitary and otherwise effective manner. The deep settling tanks employed in the Emscher district produce a sludge of this character.

It is not necessary to employ any special type of settling basin in order to ferment sludge. It may be fermented as readily a mile or more away as in the basin in which it was produced from the sewage. For fermentation to proceed satisfactorily it is necessary only that the sludge shall be kept in a tank or compartment separate from the sewage. Fermentation will not proceed satisfactorily in a tank which is immediately filled with sludge to a depth of 6 feet, but a tank which is filled very gradually will permit fermentation to proceed in a satisfactory manner.

Settling basins are, for the most part, devices which should be employed at points removed from built-up residential or commercial districts. The older types of tanks are so large as to require more space than can ordinarily be afforded where the value of property is high and a considerable amount of odor arises from them during the process of cleaning.

The newer type of tanks, which require but little space, which are nearly inodorous in operation and not emptied during cleaning, may more suitably be constructed near built-up parts of cities. The size of the installation, or, in other words, the quantity of sewage to be dealt with must be considered in this connection. A small plant might not be objectionable where a large one would cause complaint. The great depth of the newer tank and its somewhat complicated shape make it more expensive to construct than the older form of basin.

There are situations, as, for example, where sufficient land is not to be had, where the deep form may be more desirable than the shallow form. The advantage which attaches to the fermentation of the sludge, accomplishing, as it does, a substantial reduction in the bulk and facilitating an easy removal of the contained water, makes this type of sedimentation basin of peculiar value.

4. *Chemical Precipitation*

To facilitate the deposition of finely divided particles of suspended matters, recourse is sometimes had to chemicals. The chemicals which are most commonly employed are lime, alum and salts of iron. They are added in solution and, immediately forming floculi, unite the minute particles of suspended matter of the sewage into relatively large masses, which sink with comparative rapidity through the sewage. The principle is somewhat like that employed when white of egg is used to clear coffee. If the sewage is acid in character lime is usually employed and, if lacking in iron, this may be added in the form of a sulphate to add weight to the coagulated particles, causing them to settle more rapidly.

If the sewage is strongly alkaline it may be treated with the iron sulphate only; otherwise alum or basic sulphate of alumina is usually added in sufficient quantity to combine with the necessary amount of iron. If the sewage is alkaline but already containing enough iron, then alum may be substituted. Sometimes both alum and iron are added. The particular chemical used depends largely on its local market price. The amount used varies with the character of the sewage; 7 grains of ferrous sulphate per gallon of domestic sewage, from 2 to 10 grains of alum and twice that quantity of lime are not uncommon in practice.

It is claimed that the use of chemicals not only brings about a more rapid settlement, but causes more suspended matter to subside. There is also a slight reduction produced in the dissolved organic matter. In exceptional cases, where the effluent is discharged to a large stream, the use of chemicals may be suspended during certain parts of the year.

Chemical precipitation is carried on in basins of the same form and size as are commonly used for the treatment of sewage by simple subsidence. Chemical sludge is much greater in volume per unit volume of sewage than is sludge produced without chemicals, but the physical constitution of chemical sludge appears to be not materially different from that of ordinary sludge. It is neither more or less difficult to dry.

Objection to the chemical precipitation of sewage lies in the cost of the necessary chemicals used and the more elaborate plant. To dispose of the large volumes of liquid sludge it is sometimes pressed into the form of thin cakes. For satisfactory pressing it is necessary to add from 4 to 10 pounds of lime to each cubic yard of wet sludge. The ordinary means of delivering the chemicals, weighing them, dissolving them and applying them to the sewage add considerably to the cost of operating the sewage disposal plant. In most cases unpleasant odors are produced through the use of the chemicals, although the chemicals themselves may be odorless.

5. *Other Processes*

Among the less prominent mechanical methods of sewage treatment may be mentioned the hydrolytic tanks of Dr. Travis and the slate beds of Dibdin.

The hydrolytic tank resembles the Emscher tank, of which it was the precursor, in having a bottom sludge compartment. Following the tank the sewage passes through a tank containing a large number of sloping slats called "colloiders," on which the very fine suspended and colloidal matter becomes attached, increasing in thickness until it falls to the bottom as sludge. It is claimed that the removal of this finer matter without the aid of chemicals constitutes an important advance in the art of clarifying sewage.

Dibdin's slate beds consist of tanks similar to those used for sedimentation but filled with slabs of slate separated by small blocks about 2 inches thick. The beds are filled and drained much as are contact beds. In this way the sludge accumulates on the surface of the slabs and remains there until decomposed. The process being carried on in the presence of oxygen is free from the odors connected with decomposition in septic tanks and the effluent is of similar character to that from ordinary settling basins having an equal period of retention. The beds are flushed out at long intervals without apparent difficulty. According to experiments at Philadelphia, the sludge removed, which is gritty rather than slimy in its nature, is much less than by other processes of sendimentation except Emscher tanks, but the area required is relatively great.

The efficiency of the various mechanical processes for the removal of the suspended matters is shown in the following table:

	Removal of	
	Suspended Matter Per Cent.	Organic Matter Per Cent.
Coarse Screening	2—10	1—6
Fine Screening	15—35	10—25
Grit Chambers	5—10	1—3
Plain Sedimentation	60+	30
Chemical Precipitation	85	50

BIOLOGICAL PROCESSES

The biological processes which are employed in the treatment of sewage are, with the exception of septic tank and Emscher tank treatment, all designed to take place in the presence of oxygen. In fact, omitting disinfection, ultimate purification means oxidation, as has been explained in the Commission's report of April, 1910, Part III, Chapter X, page 447.

The oxidizing processes are roughly divisible into two main groups: the first contains those which require large areas of land, as irrigation and intermittent filtration, and the second those in which relatively small areas of land are required. The methods contained in the first group may be termed extensive and those contained in the second intensive processes. Included in the former are broad irrigation and intermittent filtration and in the latter contact beds and percolating filters.

1. *Broad Irrigation*

It was once supposed that the manurial ingredients of sewage could be extracted, or at least employed in agricultural processes, in a profitable way, but experience indicates that expectations of this kind are usually unfounded. In Europe and America it has been found that sewage cannot be applied to the cultivation of crops in a profitable way except where the water is needed for irrigating purposes. Sewage farms can be carried on to advantage, so far as the disposal of the sewage is concerned, where the soil is suitable, but there are many soils which are practically incapable of absorbing it. The areas required are large, and a large margin must be allowed for disposal purposes during rainy weather. Experience has shown that an acre of land is required for every 3,000 to 30,000 gallons of sewage per day or for every 25 to 500 of contributing population, depending on the climate, soil, preparation of ground, etc.; 7,000 gallons or 100 persons per acre may be taken as an ordinary rate.

Application to farm land is not practicable for New York because of the great areas of land required and the completeness with which the country within fifty miles of the city is occupied.

2. *Intermittent Filtration*

The filtration of sewage through specially prepared beds of sand is an excellent way of dealing with sewage, provided a high degree of purification is desired and the cost of the land and its preparation are not prohibitive. The application of sewage either to farm land or filters usually results in the production of an exceedingly good effluent.

Sewage may be filtered by any of several practical methods. A field may be suitably prepared by levelling, under-draining and enclosing within embankments the area of each unit serving an acre or more. After thoroughly flooding the field, the inlet is shut off and an opportunity is given to the sewage to flow downward and away through the underdrains. The field is then rested for some hours, after which another dose of sewage is applied to it.

The resting of sewage fields is an important condition to provide for. It permits bacterial changes to proceed under circumstances which are necessary to them and prevents the clogging of the pores of the filtering material. Rest is also useful as a means of bringing the sewage into contact with the oxygen of the atmosphere. When the sewage filters downward in an intermittent way it draws atmospheric air with it into the voids between the particles of the filtering material, and the oxygen is in this manner introduced into the bed. Purification takes place chiefly, but not exclusively, at and near the surface of the ground.

By this intermittent application to specially prepared beds much larger doses of sewage per acre may be employed than in broad irrigation. Rates of 50,000 to 100,000 gallons daily, or the sewage of 1,000 persons per acre, are not unusual with this method of disposal.

3. *Contact Beds*

The intensive purification of sewage is at the present time considered more economical than is purification on extensive acres of land.

The earliest intensive oxidizing process employed masses of coarse gravel or broken stone in what were termed contact beds. These beds were constructed by building water-tight reservoirs and filling them to a depth of from 3 to 5 feet with stone or gravel, ranging in size from half an inch to three inches or more in diameter. The size should preferably be uniform. In a few cases, broken brick and coal; in others tiles, and in some cinders are used.

Contact beds are operated by filling the mass of broken stone from the bottom, allowing the sewage to remain there for a period of a few hours and then drawing it away from the filtering material. It must be borne in mind that this process is not one of filtration, but of oxidation. It is believed that the solid particles of which the bed is composed are covered with bacteria and that these minute organisms are instrumental in combining the oxygen which is present with the organic matters of the sewage.

As to the rates at which sewage may be applied to contact beds, 600,000 to 1,000,000 gallons per acre, daily, are common.

Where more thorough purification is demanded the sewage is put through two or even three sets of beds. With double contact treatment the area required is necessarily greater, and in round numbers may be taken as one acre to every 400,000 or 500,000 gallons per day. Single contact beds reserved for storm water may operate for limited periods at much higher rates, perhaps 3,000,000 gallons per acre daily.

When properly built and operated, contact beds are capable of making sewage non-putrescible. In other words, sewage which, if allowed to stand alone or mixed with river or harbor water would putrefy and give off offensive odors, can by their means be made practically incapable of further decomposition. The contact bed is, in reality, a means of hastening the process of decay under circumstances which are more or less within control.

Contact beds produce but little odor. It may be urged against them that they are comparatively expensive and they require comparatively large areas of land. They should be situated at a distance from built-up residence or business districts.

Contact beds are self-cleansing when well built and managed. After long intervals of time it is sometimes necessary to replace the material of which they are made, but this contingency may be indefinitely postponed, if not completely eliminated, by scientific design and operation.

4. *Percolating Beds*

The most approved method of oxidizing sewage at the present time is by means of percolating beds, sometimes called sprinkling or percolating filters. Oxidizing beds of this kind are not filters in any sense of the term. There is usually more suspended matter present after the sewage has passed through them than before.

A sprinkling filter may be briefly described as a bed of broken stone or gravel from 1 to 3 inches in size. Beds of this kind need no water-tight support at the sides, as do contact beds. They are usually from 5 to 9 feet in depth and should be well underdrained and provided with a carefully arranged apparatus to distribute the sewage evenly over the stones, for it is desirable that all parts of the beds should receive an equal dosage.

The sewage may be distributed on the bed by sprinkling from fixed nozzles properly spaced, from small holes in radial pipes swinging about a center or from troughs or wheels with buckets which travel back and forth on rectangular beds. In the movable sprinklers the motion may be derived from the reaction or weight of the sewage, or it may be imparted from a motor. Fixed nozzles are more distinctive of American practice and rotary, or traveling distributors, of European practice. In either case sprinkling on any one part of the surface should not be continuous, and the hourly rates of application to different parts of the surface should be uniform.

The sewage which is sprinkled over the bed percolates slowly downward until it reaches the under-drains, when it is carried away. Oxidation takes place upon the surface of the stones.

The process of oxidation which takes place in the sprinkling filter is apparently the same as that which occurs in contact beds. There is this difference, however, that the particles of gravel or stone are never submerged in the percolating bed, but are kept continually wet. Filtration may be continuous or intermittent, the intervals between doses being a few minutes. The oxygen is derived from the atmosphere, there being in well-constructed percolating filters a circulation of air through all parts of the bed.

Sprinkling filters are more efficient than contact beds in that a larger quantity of sewage can be purified upon a given area of land. This may be taken at from 1½ to 2 million gallons per acre daily, depending on the quality of the sewage, the depth of the filter and the size of the material of which it is made.

Among the disadvantages which attach to sprinkling filters is odor. Owing to the sprinkling of sewage into the atmosphere, the odor is especially objectionable in those cases where the sewage is in an advanced stage of putrefaction when it is applied on the bed. Another disadvantage is in the fact that great numbers of small annoying flies commonly infest the works, hatching out within the filter beds. It is not known that the flies are ever concerned in producing sickness, but they are often so annoying as to cause serious complaint.

Neither the mechanical nor oxidizing treatment of sewage is capable of removing all the bacteria.

5. *Other Processes*

Attempt was made by the late Colonel Waring and has been made by others to make use of atmospheric oxygen by the direct application of air in the purification of sewage. Although beneficial results have been obtained in this way, they have generally not been commensurate with the expense involved. Recent experiments by the Massachusetts State Board of Health in this line have been favorably reported in which air is discharged into the bottom of a tank 5 feet deep containing vertical layers of slate. Twenty-five thousand cubic feet of air per hour injected for five hours at a total cost of less than $2.00 are said to not only render the sewage quite clear and inoffensive, but to produce a sludge, digested under inoffensive conditions, that is free from objectionable odor, granular and readily removed. The real processes of purification are apparently carried on in the films of deposit that form on the surfaces of slate and, as they become decomposed, slough off.

In short, the direct application of atmospheric oxygen to sewage, while it may aid in removing odors and promote conditions favorable to purification, does not appear to have any substantial immediate effect. Final purification is effected only through the agency of living organisms, and this takes hours, or even days, to accomplish.

Nascent oxygen or ozone may, however, act on organic impurities much more promptly. The action is in the nature of sterilization. Various processes have been devised to treat sewage in this way, but the cost has usually been excessive.

Disinfection

In order that sewage may be rendered harmless to health, it is sometimes disinfected. Disinfection can be accomplished by applying bleaching powder. The process can be carried on on any scale. It has been claimed that sewage does not need any preparation for the disinfecting treatment, but experience shows that the removal of at least the larger suspended particles is a desirable procedure before the disinfectant is used.

The amount of bleaching powder or hypochlorite required depends upon the strength of the sewage and on the proportion of impurities to the "available chlorine" in the commercial chemical used. The available chlorine should amount to about a third of the commercial salt. The amount of bleach required per million gallons of fresh sewage may generally be taken at from 100 to 250 pounds; for septic sewage 250 to 400 pounds, and for sprinkling filter effluents from 75 to 100 pounds. The total cost of the process ranges from 75 cents to $4.00 per million gallons.

The use of liquid chlorine in place of bleach is a recent improvement in permitting greater precision in the measurement of the dose, a more complete use of the chlorine and freedom from solid residue.

Sewage may be disinfected by the passage of an electric current through the liquid. This method has been applied with more or less success in a few small towns, but the cost per million gallons (about $9.00) has been too great for its general adoption.

Sludge Disposal

The disposal of the sludge removed from the sewage by the foregoing methods of treatment is often a difficult problem. In volume it ranges from 1 or 2 cubic yards per million gallons of sewage (70 per cent. water) in the case of Emscher tanks to 20 or 30 cubic yards with chemical precipitation containing perhaps 96 per cent. of water. Unless dumped at sea or run onto farm lands direct as a fertilizer, which is rarely done, the first problem is the reduction of the moisture so as to reduce the bulk, enable it to be handled conveniently and reduce the amount of odor produced.

This may be accomplished by drying in the air, by artificial heat, by filter pressing or by centrifugal machines. The first of these require considerable land, with the probability of nuisance, and the others require expensive machinery.

If spread upon the land from 0.1 to 0.2 acre are usually required for every 100 cubic yards of sludge produced in a year.

The cost of filter pressing is from 10 to 25 cents per ton of wet sludge or $1.00 per ton of pressed cake; the cost of centrifugalizing about 10 cents per cubic yard of wet sludge or 45 cents per cubic yard of product, and the cost of further drying in a rotary drier about 75 cents per ton of dried material.

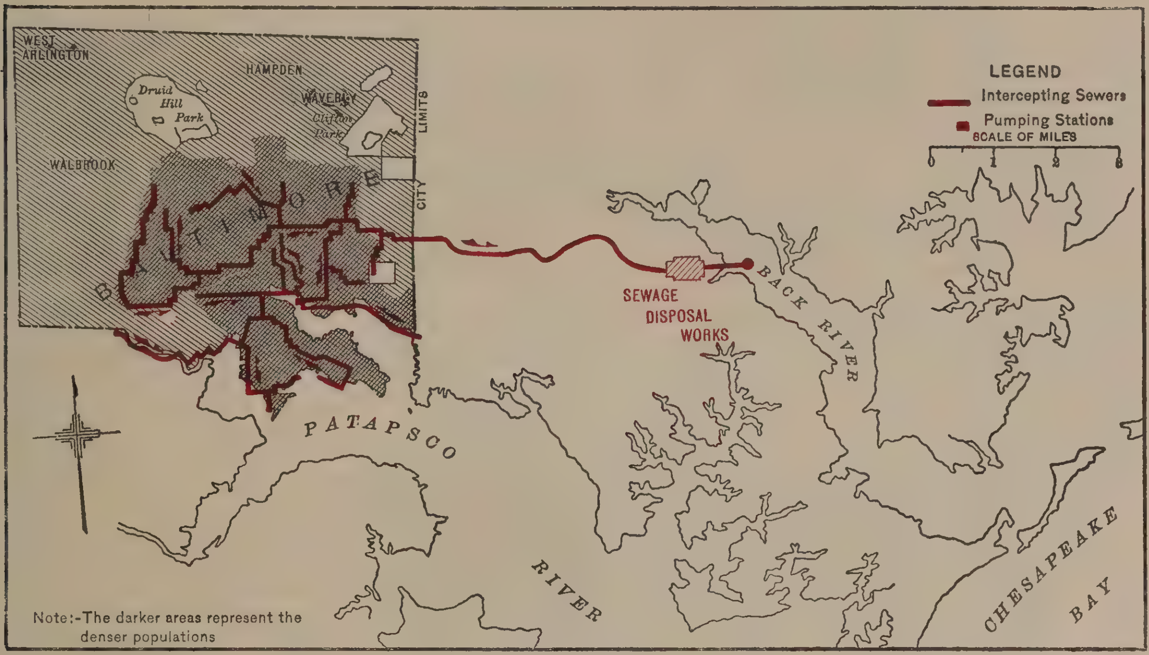
Under favorable conditions dried sludge may have a certain market value as fertilizer. The value of air-dried sludge for this purpose is nominal only, but when specially prepared after drying in a rotary drier it may find an occasional market at $5.00 or $6.00 per ton. The revenue from this source added to that from the sale of grease that may be recovered in some instances may offset the cost of sludge disposal or possibly net a small profit.

EXAMPLES OF MAIN DRAINAGE OF VARIOUS LARGE CITIES

Baltimore

Baltimore, Md., with a population of 558,483 according to the census of 1910, covers an area of 32 square miles. Its surface is hilly, affording rapid velocities in gutters and sewers. The city is divided by Jones Falls, a stream that runs in a southerly direction to the harbor. The harbor is an arm of the Patapsco river, projecting into the heart of the business center of the city from Chesapeake bay, 12 miles away. The harbor is without appreciable current and has a tidal range averaging about 16 inches. The condition of the harbor water has been the subject of complaint for many years.

Parallel to the Patapsco and a short distance north of it is Back river, an estuary of considerable width for several miles above its mouth. Baltimore was without a comprehensive system of sewerage until plans were made for the construction of a separate system and disposal works after the fire which destroyed a large part of the city in 1904. Several million dollars had been spent on storm water outlet drains, many of them of large size, and special permits had been granted allowing the property owners to discharge domestic sewage into them. In the newer sections of the city, contractors had provided private sewers for blocks of houses which they built and obtained permits to discharge the drainage into the natural water courses. The usual practice was to discharge house sewage into large cesspools with open or permeable bottoms. These were cleaned when necessary, the volume removed in 1909 averaging 169 wagon loads per day. The cesspools were cleaned by contractors with so-called odorless excavators, loads of about 200 gallons being removed and dumped upon scows holding about 450 loads each.



Note:-The darker areas represent the denser populations

FIG. 4—BALTIMORE

The household sewage collected on the separate system is passed through settling tanks, sprinkling filters and subsequent settling tanks before discharge into the Back river.

The scows were towed to distant points where the sewage was pumped into lagoons provided by the owner of the land. From the lagoons the concentrated sewage was bailed into tank carts and distributed on land.

The sewage works when built consisted of a separate system, collecting the domestic sewage of the city into a high and a low interceptor, the sewage being pumped from the lower to the higher at a suitable point. The works are situated about 4½ miles east of the city boundary on the shore of Back river. The process of disposal comprises sedimentation, screening, sprinkling filters and subsequent settling basins. The ultimate population provided for was approximately 1,000,000. The works were well under construction at the end of 1913.

BOSTON

A description of the main drainage works of Boston is given in Part III, Chapter II, Section 4 of this report.

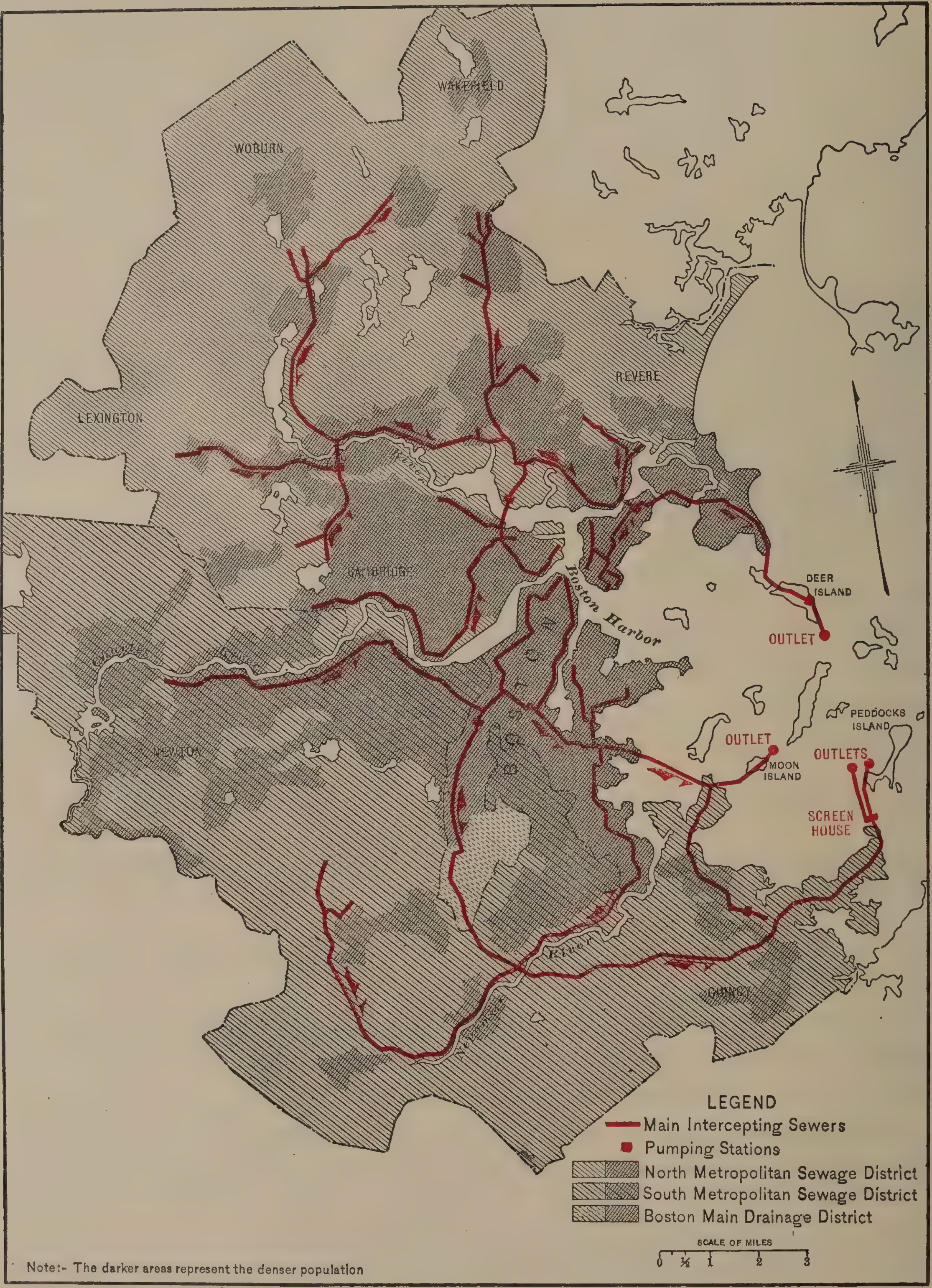


FIG. 5—BOSTON

The sewage of Boston and vicinity is discharged through three principal outlets situated in the outer harbor. The North Metropolitan sewage is passed through coarse screens and discharged just beneath the surface of the harbor water. The South Metropolitan sewage is screened and discharged about thirty feet beneath the surface. The sewage of Boston is stored in reservoirs and discharged on outgoing tidal currents.

CHICAGO

Chicago is situated upon the comparatively low-lying land near the south end of Lake Michigan. The natural drainage is toward the lake, which affords the only source of water supply for Chicago and its neighboring municipalities. In order to protect the water supply, and incidentally provide water transportation to the Mississippi river, a canal has been built whose effect is to reverse the direction of natural drainage and provide means for carrying away the sewage of the city.

The works, which are intended for the sewage of three million people, include the construction of the canal, the improvement of the Chicago river, which, to all appearances, is a prolongation of the canal, the construction of intercepting and collecting sewers, the building of intakes from the lakes and pumps to provide the large supply of water needed to maintain suitable currents in the canal.

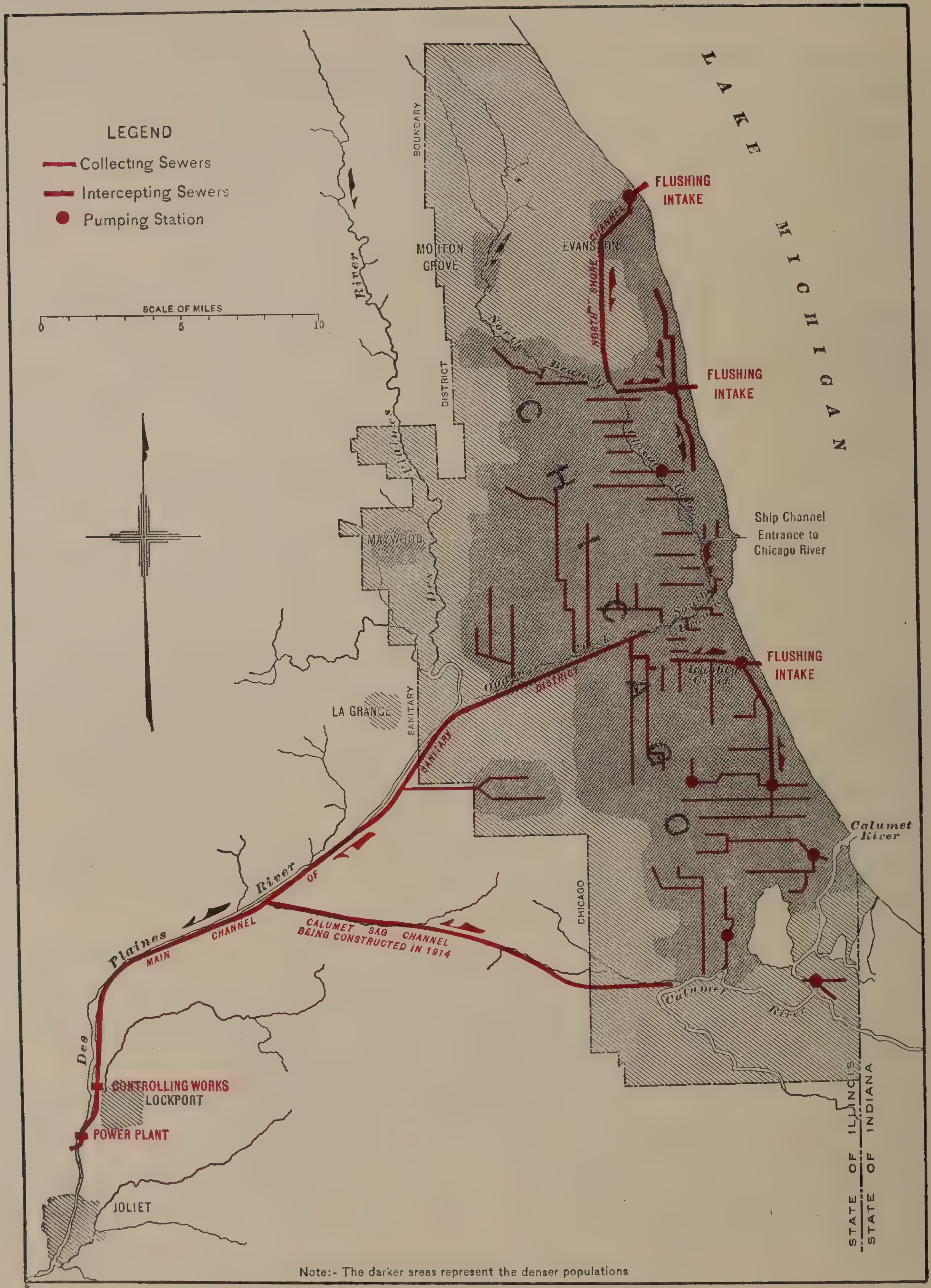
The disposal works for the sewage of the northern and southern districts and environs are not yet complete. Some sewage from urban and suburban populations discharges into the lake, and it is intended that the pollution of the lake from these sources shall be prevented by the construction of works which will be co-ordinated with the main drainage scheme which has been built.

The total cost of the work has been over $40,000,000 thus far. The construction of the Chicago drainage canal was carried on by a commission or board of trustees known as the Sanitary District of Chicago. The district was organized under a general State law for the creation of sanitary districts, passed in 1889. The total area covered by the board's jurisdiction is 358.08 square miles.

The main canal or channel of the Sanitary District is 28.05 miles long. The first work put under contract was in 1892 and water was let in to the channel January, 1900.

It is estimated that the population of the Sanitary District will have reached 3,000,000 between the years 1920 and 1922, and to dilute the sewage of 3,000,000 people will, under the State law, require 10,000 cu. ft. of water per second as a minimum. The intended capacity of the canal was 600,000 cu. ft. per minute.

In a report of the Chief Engineer to the Board of Trustees of the Sanitary District, October, 1911, the statement is made that it is questionable whether the capacity of the canal will be sufficient properly to dilute the sewage of 3,000,000 people together with the large quantity of manufacturing wastes that are discharged from the sewers into the different branches of the Chicago river.



Note:- The darker areas represent the denser populations

FIG. 6—CHICAGO

The crude sewage of Chicago is discharged into the Chicago river whose current has been reversed and made to flow through a channel constructed for the purpose into the Des Plaines river and thence to the Mississippi.

The sewage is discharged into the Chicago river and its immediate tributaries in Chicago in crude condition and through numerous outlets some of which are very large. Water is pumped into the river for flushing purposes in the north end of the city through a 16-ft. conduit connecting with the lake. The entrance to the Chicago river which is used for shipping, is near the center of the city. A pumping station, discharging into the canal through a 20-ft. conduit is situated somewhat to the south of the more thickly built-up section of the city. The water supplies are taken from cribs running from two miles to four miles out into the lake and at various points along the water front opposite the built-up sections.

The Calumet territory is to the extreme south of the city and is partly in the State of Indiana. The Calumet area is intersected by the Calumet river—a small and usually sluggish stream whose level is influenced by Lake Michigan. It is intended by the Sanitary District of Chicago to construct a channel with a capacity of 2,000 cu. ft. per second to reverse the flow of the Calumet river and cause its waters to flow into the main channel of the Sanitary District.

The canal of the Sanitary District is avowedly an open sewer in which the crude sewage of Chicago is poured and diluted with sufficient water from Lake Michigan to prevent excessive nuisance. This method of disposing of the sewage was contemplated when the Sanitary District Act of 1889 was passed by the State Legislature in order that the Sanitary District of Chicago could be created. Experience in Europe and America checked by observations upon the dilution of that part of the sewage of Chicago which had for some years been discharged into the Illinois and Michigan canal led to the opinion that a flow of at least 3.3 cu. ft. per second of clean water should be provided for every thousand people sewering into the canal. The question has always been considered from the standpoint of nuisance and not as to whether the water was so polluted as to destroy fish life or affect the health of persons who came in contact with it. The minimum figure for dilution was based largely on the assumption that domestic sewage was to be dealt with and is said not to provide a wide margin for industrial wastes or for the disposal of deposits of sludge in the river or canal.

According to the report of the Chief Engineer for 1911, the oxygen in the water of the canal is frequently exhausted at Lockport and continues to be exhausted for ten or fifteen miles; while odors are distinctly noticeable at Lockport and as far down as Joliet, they are not considered to have assumed the proportions of a definite nuisance.

It is estimated that the suspended matter in the sewage which is discharged into the river and main channel from human sources alone amounts to over 137,000 tons of dry material, and of this about 40 per cent. may settle. Roughly this represents about 640,000 cu. yds. of liquid sludge per year.

COLUMBUS

The city of Columbus, Ohio, covers an area of seventeen square miles, and in 1910 had a population of 181,548. It is situated just east of, and opposite, the confluence of the Olentangy and Scioto rivers. For a distance of about one hundred miles below this point, no water is taken for municipal supply. Above the confluence the Scioto

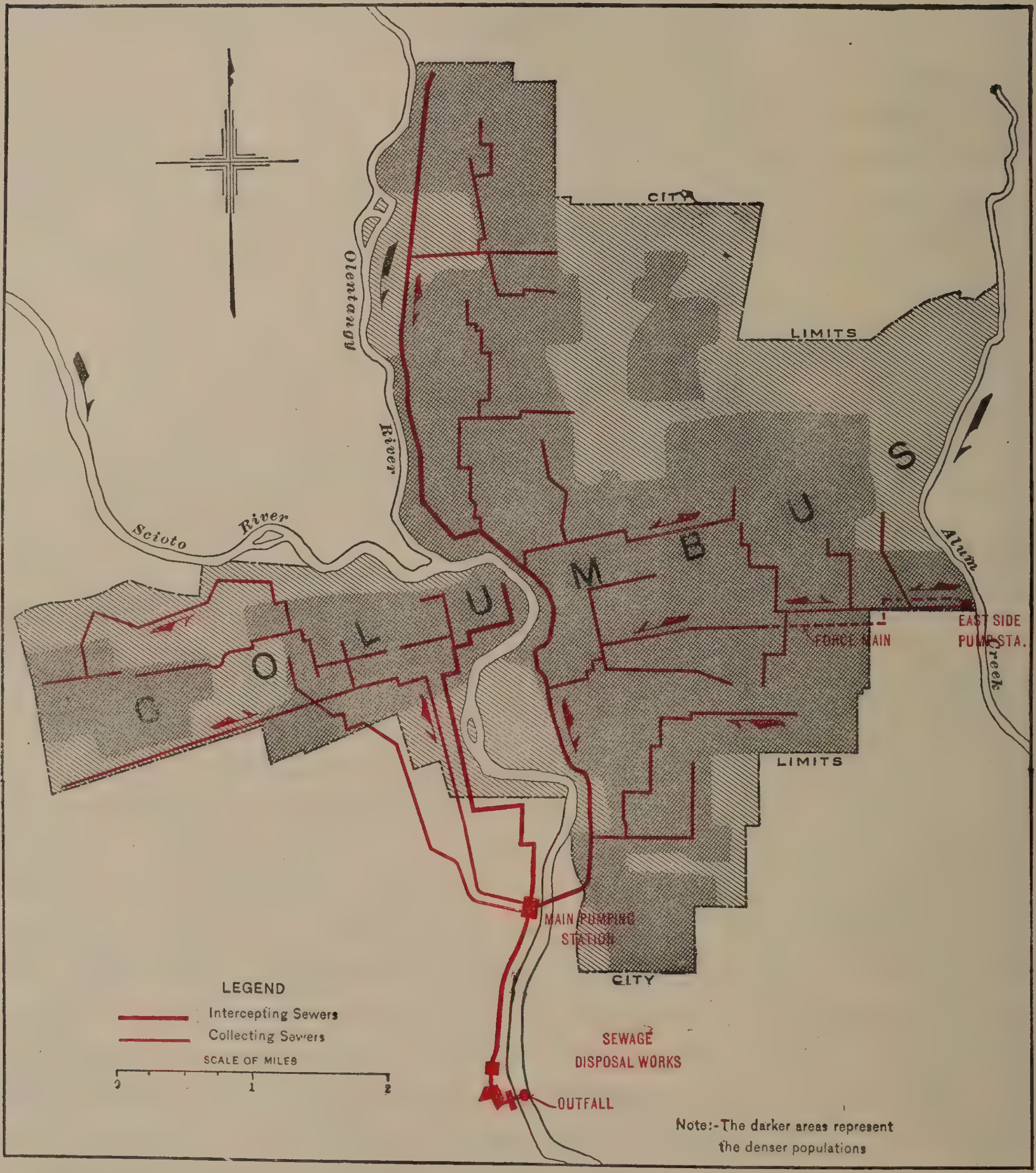


FIG. 7—COLUMBUS

The sewage works consist of septic tanks and sprinkling filters.

drains 1,050 sq. miles and the Olentangy 514 sq. miles. During periods of dry weather the entire flow of the Scioto is drawn for water supplies by towns above Columbus and is returned as sewage. Before the disposal plant was built, the additional discharge of the sewage of Columbus resulted in stagnation and foul smelling pools. Similar conditions of nuisance obtained in Alum Creek, which drains the extreme eastern section of the city and enters the Scioto river several miles below.

Steps were taken to correct the polluted condition of the river within the limits of Columbus in 1888, when an intercepting sewer was constructed to carry the sewage to a point below the city. Experimental studies in the purification of sewage were made between 1903 and 1905. As a result of this investigation it was decided to construct a plant consisting of septic tanks, sprinkling filters and settling basins.

Part of the sewerage is on the combined and part on the separate system. The maximum capacity of the main sewer leading to the works is 40,000,000 gallons per day. This provides for the ordinary dry weather flow and 0.02″ per hour of rainfall over the drainage area. In 1912, 2,789,660 gallons of the total daily amount of sewage were pumped, the main pumping station being in service about 220 days in the year. For the remainder of the time it was not needed or was shut down for lack of funds.

At the pumping station the sewage passes through two cage screens with openings of 1-inch and ½-inch respectively. The screenings are spread upon the adjoining land. The pumping station is about 2.3 miles below the center of the city. The lift is 28 feet. A 48-inch cast-iron force main conveys the sewage from the pumping station to the purification works a little over a mile away. The disposal works are situated upon an area of flat ground 46 acres in extent surrounded by a levee for protection during floods. The plant cannot be operated during flood stages of the river as the elevation of the filter beds and settling basins is below high water level. At such times the dilution of the sewage by the river water is so great that treatment is not considered necessary.

The river varies greatly in volume, ranging from 30 cu. ft. per second to 50,000 cu. ft. per second. Under dry weather conditions it is about equal to the flow of sewage from the city.

At the works the sewage is delivered to four primary septic tanks which have a combined capacity of 2,840,000 gallons. From these it passes to two secondary tanks with a combined capacity of 5,200,000 gallons. Each tank is divided in two parts by a submerged concrete baffle 8 ft. high intended to retard the motion of sewage at the bottom. The floor slopes to an open channel at the center which leads to a blow-off to the river. The septic tanks are not covered. The combined capacity of the tanks is 8,040,000 gallons and, as they are designed for a flow of 20,000,000 gallons, they will provide storage for 9½ hours. As operated, sewage is stored for about 8 hours.

From the secondary tanks a 60-inch reinforced concrete conduit 625 feet long conveys the sewage to a distributing well at the center of the filter beds. These are in the form of six triangles about 2½ acres each, forming a hexagon. The sewage is distributed by nozzles spaced 15′4″ apart. There are 528 nozzles to a bed. Four of the six beds have been constructed with a normal capacity of 30,000,000 gallons per day.

The filtering material is 5 feet thick and is composed of broken stone. The size varies from 3 to 4 inches for a foot at the bottom; the remainder is 2 inches in diameter.

After passing from the sprinkling filters, the sewage flows to two settling basins having a combined capacity of 2,000,000 gallons and an area of two acres each. When handling 20,000,000 gallons of sewage per day the period of flow is about 2½ hours. The sewage is conducted away from the plant by three outlet conduits 5½ feet in diameter which lead to a chamber containing flap valves and sluice gates.

The settling basins are emptied by a pump operated by a gas engine. The sludge is not utilized, being flushed to the river or to gravel pits in the vicinity.

Fermentation proceeds at times so actively in the primary tanks as to interfere with the process. The odor is offensive near the tanks and near the filters. The sprinkling filters give the best result under heads of 4.7 and 9 feet, discharging for fifteen minutes under each head with fifteen minutes of rest between. The effluent is practically nonputrescible but carries about the same amount of sediment as when leaving the septic tanks.

Providence

The City of Providence, with a population in 1912 of 235,600, covers a hilly area of 18.3 square miles near the head of the Providence river in the State of Rhode Island. The population served by the sewers is 206,000 and the sewage contains much manufacturing waste from woolen mills, bleacheries, dye houses and jewelry factories.

Owing to the increasing pollution of the river and the several tributaries which flow through the city and the threatened contamination of extensive oyster beds along the river below Providence and in Narragansett bay, sewage disposal works were constructed after studies of European methods of purifying sewage were carried on in 1884.

The works of main drainage include intercepting sewers which collect and carry the sewage of the city to Fields Point, at the mouth of the river somewhat below the city, where pumps and a chemical precipitation plant were originally constructed. In 1912 the amount of sewage treated was about 21 million gallons per day, which is about 6 times the volume for which the works were originally designed.

For some years the works were operated on the principle of chemical precipitation with sludge pressing. They have recently been somewhat reconstructed and the sewage is now settled and treated with bleaching powder solution. The sludge is pressed and the cake is carried away by scow. The effluent from the settling tanks is run into storage tanks and discharged directly into the river on the ebb tide. The discharge takes place beneath about 35 feet of water. The bleaching powder solution is used in the proportion of about 144 pounds of hypochlorite per million gallons of sewage. About 5.8 parts per million of available chlorine are added.

The sludge is pumped by ejectors to storage reservoirs from which it flows by gravity to forcing receivers 8 feet in diameter by 12 feet in length, which operate under 60 to 80 pounds pressure and feed the filter presses. The ejectors and forcing receivers are run by air pressure generated by an air compressor which is actuated by a motor. There are 18 presses of 43 to 54 plates each. Cakes are 36 inches square and from ¾ to 1¼-inch thick. Lime is added to the sludge before pressing in the proportion of 79 pounds per thousand gallons of sludge. The moisture in the wet sludge is about 91 per cent. There were 20,436 tons of sludge cake produced in the year 1912 containing 29.5 per cent. of moisture.

The cost of sedimentation and disinfection per million gallons of sewage treated is given as $2.85 and the cost of sludge disposal $2.49 per million gallons of sewage treated. In the year 1912 there were 1,758 gallons of sludge produced per million gallons of sewage. The process removes about 48 per cent. of the suspended matter from the sewage. The cubic contents of the settling basins up to the flow line is 3.96 million gallons and the capacity of the storage tanks 7,170,000 gallons. There were discharged, without treatment, in the year 1912, 81 million gallons of storm water.

The total number of bacteria removed by the process varied in the year 1912 from about 60 per cent. to 99.9 per cent. according to averages stated for each month. The efficiency of the disinfection process, based on relative number of B. coli in the sewage and effluent, is stated as 97.4 per cent.

Washington

The city of Washington, D. C., with a population of 331,069 in 1910, is located on the east side of the Potomac river, just above the mouth of the Anacostia river. Except in the northerly portion, the city lies on low, flat ground and there was formerly much damage done by flooding during periods of high water in the river. The mean range of tide is 2.9 feet, but during freshets the rise may be 10 or 12 feet above mean low tide. The Potomac, just below Washington, drains 12,555 square miles, of which 83 drain to Rock creek and 169 to the Anacostia river. The average flow during the driest months of the year is 2,300 cubic feet per second; during the wettest months 52,170 cubic feet per second, and during the whole year 20,600 cubic feet per second.

The sewerage of the city may be said to date from 1871, when a board of public works was created. In course of time various defects developed and there were complaints from odors due to lack of ventilation and from pollution of the water courses. In 1885 the sewage was practically all discharged at four outlets. In accordance with the recommendations of a board of consulting engineers in 1890, storm drains were constructed in the low-lying sections, the polluted canals were filled and intercepting sewers were built to deliver the sewage at a central pumping station on the Anacostia river. From this station the sewage was carried by three siphons of 48-inch diameter for a distance of 2,680 feet under the river and thence by an outfall sewer 9 feet 4 inches by 8 feet 4 inches and 15,483 feet long along the east shore of the Potomac to an outlet discharging at the bottom of the river about 500 feet from shore.

A large area, containing a population of about 30,000, is drained on the separate system, but a more thickly settled portion, containing about 320,000 people, is sewered on the combined plan.

On reaching the pumping station, the sewage is passed through a coarse screen, a small sedimentation chamber and a skimming tank and then pumped to the outfall.

The volume of sewage produced in the year 1912-13 amounted to 23,518,000,000 gallons and the amount of storm water 839.8 million gallons. The sewage pumped is 92 to 114 cubic feet per second.

The average ratio of sewage to water is 1 to 45 in October and 1 to 234 in March. The minimum amount of oxygen near the outfall is about 50 per cent. and in this vicinity fishing is good.

WORCESTER

Worcester, one of the largest manufacturing cities in the State of Massachusetts, with a population in 1910 of 145,986, is situated in a hilly district whose natural drainage passes by several small streams to Millbrook, which, in turn, empties into the Blackstone river, just south of the city. On the course of the Blackstone toward Narragansett bay there is a considerable fall in elevation which furnishes power to numerous mills with dams and mill ponds. Opportunities are therefore afforded by the river for the sedimentation of silt material washed down from Worcester and for evils of stagnation to occur.

In 1867 the Legislature of the State granted the city the privilege of using the

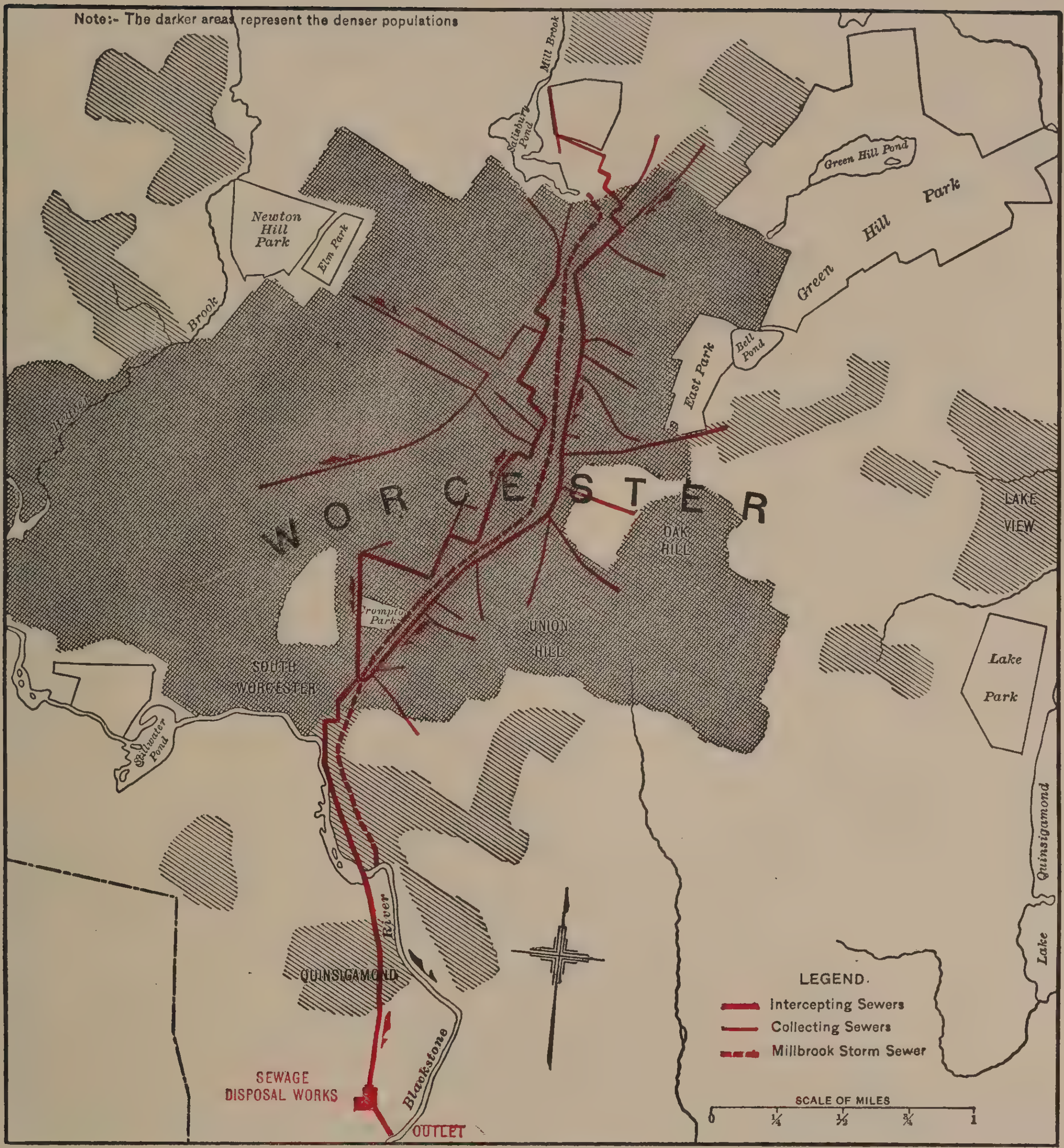


FIG. 8—WORCESTER

Part of the sewage of Worcester is disposed of by chemical precipitation and part by sedimentation followed by intermittent sand filtration, the effluent being discharged into the Blackstone river.

brooks for the reception of sewage and the watercourses in the city which have been used for this purpose have been enclosed, the last section of the Millbrook covering being completed in 1894.

Complaints from property owners on the Blackstone river below Worcester began to be made in 1870 and these resulted in studies which were protracted for many years. Among the means which were considered for the protection of the Blackstone was the construction of a trunk sewer to sea near Boston. When the population of the city reached 70,000 in 1886, the Legislature passed a statute requiring Worcester to purify its sewage before discharging it into the Blackstone river. After numerous reports from experts and the recommendation of various methods of solving its sewage problem, Worcester finally adopted chemical precipitation and intermittent filtration as the process for the disposal of its sewage.

The first sewers were built on the combined plan and designed to discharge into the Blackstone Canal which extended into the heart of the city. After the canal had ceased to be used for boats, the city took it, walled it up, arched it in and called it the Millbrook sewer.

About 1897 in order that the purification plant might be operated to better advantage, it was decided to make a complete separation of sewage and the surface water in the outlying districts and to build interceptors in the main and business parts of the city; one on each side of the Millbrook sewer and one extending into the business part of the city. The three interceptors were combined and connected with the main sewer which extended to the purification plant. The dry-weather flow was taken by the interceptors and the Millbrook sewer was left for the flow of the water from ponds and other natural tributaries to the north of the city. At times of storm, the interceptors take the first street washings up to their capacity, the excess overflowing to Millbrook creek.

At the disposal works the sewage is passed through grit chambers which remove about one-tenth of a cubic yard of solid matter per million gallons of sewage, the deposits being disposed of on waste land. After passing through the grit chambers, the sewage is treated either by intermittent sand filtration or by chemical precipitation with milk of lime, the quantity of sewage treated in each way during the year 1912 having been 11,500,000 gallons per day by chemical precipitation and about 4.3 million gallons per day by filtration. The quantity of sewage which can be treated on the filters is limited by the capacity of the area required. The strongest sewage is selected for filtration, for the reason that this method gives a higher degree of purification than does chemical precipitation. The area available for filtration is about 73 acres and the flow per day about 58,000 gallons per acre. Before the sewage is passed upon the sand filters, it flows through one of two settling basins, giving a detention period of one-half hour.

The sludge produced in this way is about 3,750 gallons, containing 95 per cent. of moisture, per million gallons of sewage. In the year 1912 solid matter to the extent of 320 cubic yards per acre or 15 cubic yards per million gallons of sewage filtered was scraped from the filters. The purification effected by the sand filters, measured by the albuminoid ammonia, amounts to about 87.1 per cent. and measured by the dissolved organic matter 66.7 per cent.

In the year 1912 chemical precipitation required 1,902 tons of lime and the sludge produced amounted to 4,551 gallons per million gallons of sewage treated. Most of the sludge is pressed in filter presses with the formation of about 11,000 tons of cake which is hauled to a sludge dump. Farmers in the vicinity take a small proportion to be used as fertilizer. The efficiency of the precipitation process as shown by the albuminoid ammonia is a removal of 77.8 per cent. of the suspended organic matter.

The cost of chemical precipitation and sludge disposal in the year 1912 was $8.44 per million gallons. The purification effected by the entire plant, as measured by the albuminoid ammonia, amounted to 57.7 per cent. and by suspended organic matter 87.2 per cent.

There are said to have been no recent complaints from the residents of the towns below. It is expected, however, that with the rapid growth of population and manufacturing, the plant will not be able adequately to cope with the sewage problem and that steps will have to be taken toward a larger plant along lines of greater efficiency as indicated by the results of experiments which have recently been conducted.

BERLIN

Berlin is situated in the midst of a flat, low-lying, sandy plain whose natural drainage system includes the river Spree and a large number of small lakes. The public waterways include many miles of artificial canals. The city is divided into 12 parts for the purpose of sewerage with a central collecting station at the lowest point in each. From this lowest point the sewage is pumped to farm lands which lie at a distance to the north and south of the city.

The Berlin sewerage system serves the city of Berlin, proper, and certain parts of the contiguous suburbs. At the close of the fiscal year 1912, the territory served covered 15,000 acres and had a population tributary to the sewers of 2,182,391. The volume of sewage was 80 million gallons per day, which is equivalent to 36.7 gallons per capita per 24 hours. The sewage is collected on the combined plan.

The sewage, on arriving at the central collecting stations, is passed through grit chambers and, in some cases, screens, before being pumped to the farms for disposal. In 1912 the sand and other material removed in the grit chambers amounted to 3,400 cubic yards. The sewage is pumped through force mains to the irrigation fields which lie to the north and south of the city at an elevation of from 65 to 100 feet above the level of the pumping stations. In 1912 there were 0.84 million gallons of sewage from the suburbs and 29,270 million gallons of sewage from Berlin, making nearly 30,000 million gallons in all pumped to the farms.

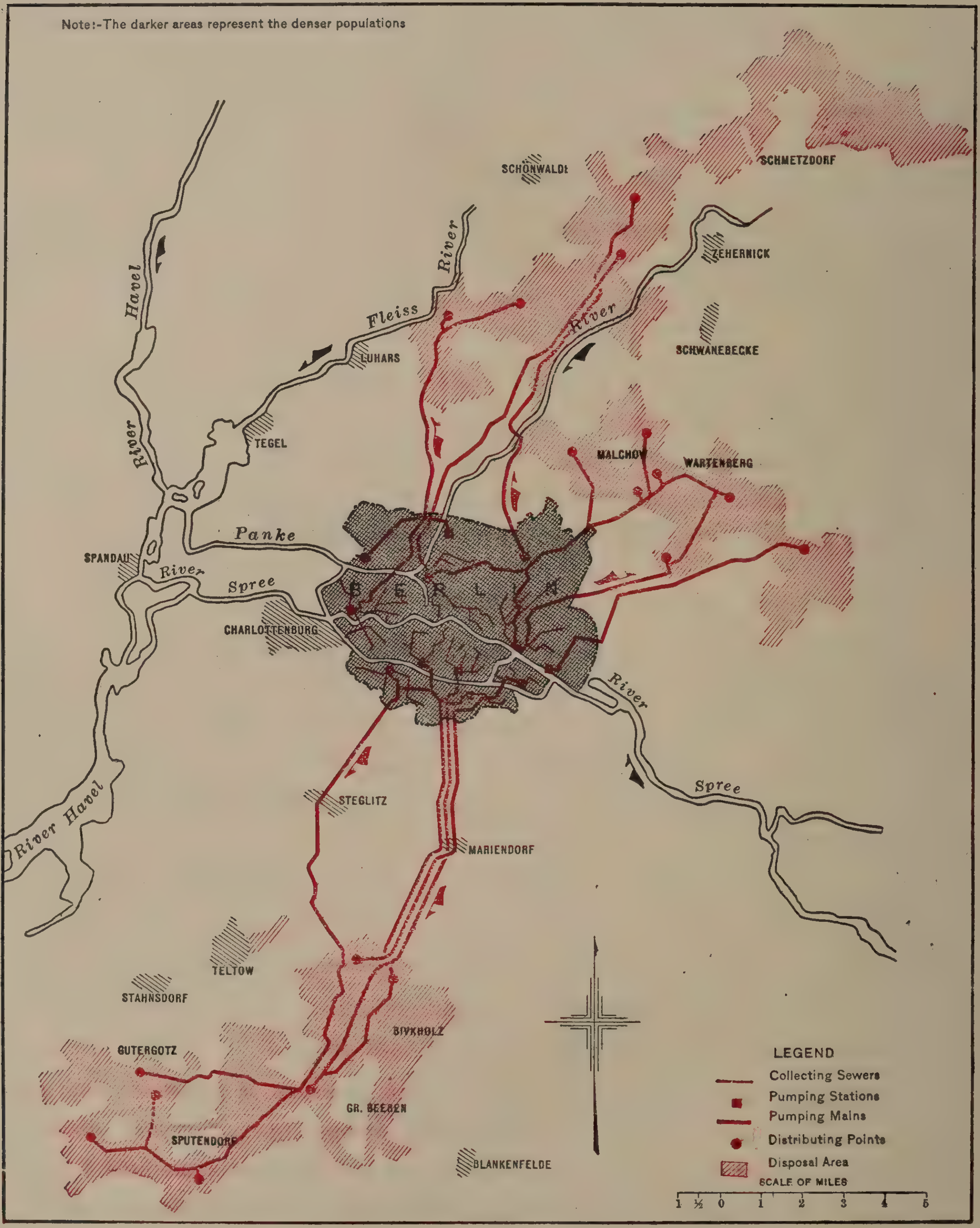


FIG. 9—BERLIN

The sewage is pumped to extensive areas of land to the north and south of the city where it is utilized in the cultivation of crops.

The force mains vary from 5 to 17 miles in length. The usual construction is welded wrought iron socket pipe in lengths of about 20 feet.

The sewage is discharged through sluice valves upon the sewage fields at points from which it can flow by gravity until finally disposed of. The method of application varies with the formation of the ground. The deeper slopes are grown to meadow. The lesser inclines are laid out in vegetable beds and the levels are banked up into settling pools. The sewage is distributed from the sluice valves partly through clay pipes, but mostly through open ditches about 1½ feet deep. In the settling pools the sewage is allowed to fill to a depth of about 1 foot, whereupon it is turned off and the contents allowed to seep into the ground. That which is applied to the meadows and vegetable beds is supplied as rapidly as the earth will absorb it.

The settling pool method of disposal is employed only in winter. The ground covered by the pools is usually sown to grain in the spring. The fields are drained by pipes generally laid about 4 feet below the surface, this depth having proved sufficient to cleanse the water and is found suitable for discharging the effluent into the public waterways.

When the present system of sewage disposal was adopted, it was thought by some that the earth would soon become saturated with the sewage matters, but this is said not to have proved to be the case. The sewage farms are about 43,400 acres in extent and sewage is regularly applied to about one-half of this territory. About 16,000 acres are laid out in vegetable beds and settling pools and about 5,000 acres are in meadow. The balance includes 38 acres of fields where pisciculture is carried on; 247 acres are devoted to forestry.

The water which drains from the sewage fields is subjected to constant chemical and biological examination. Tests are also made periodically of the waters of the Spree. The health of the people who live on the sewage farms is carefully watched. The records are published annually and confirm the belief that the sewage fields are satisfactory from a hygienic standpoint.

Upon its passage through the earth, the sewage parts with most of its organic impurities, but the effluent sometimes contains more nitrogen than is commonly met with in natural streams. This has encouraged the growth of algae to such an extent that some of the water courses have become partly closed. When the algae die and decompose, minute forms of animal life feed upon them and the total mass of these living organisms may become great.

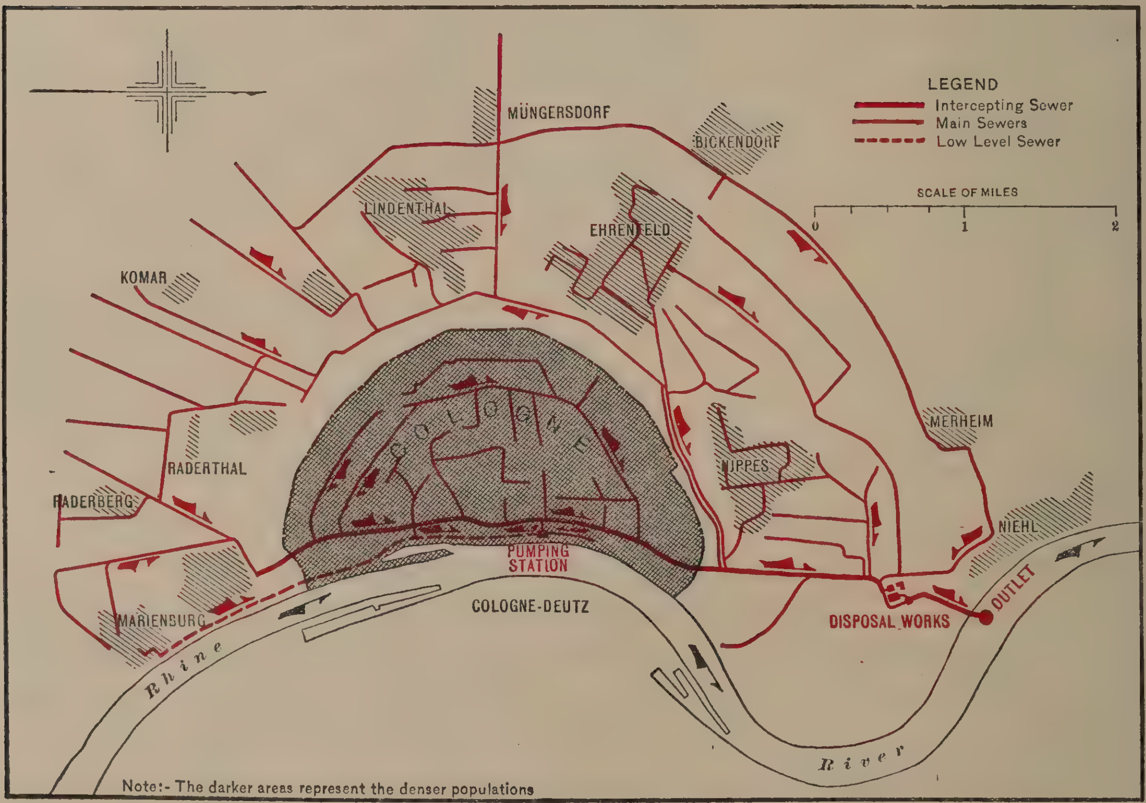
There are no better farms from which to judge the possible profit to be realized from applying sewage to land. About one-half of the fresh vegetables consumed in the city of Berlin is said to be derived from the sewage farms.

The cost of construction of the sewage works, including street sewers, pumping stations and force mains, was $24,900,000 up to the end of the fiscal year 1912. The sums expended on the farms, including purchase price, drainage and carting, was $18,160,000. The total indebtedness was about $26,130,000, or $12.62 per head of the population of Berlin concerned.

The gross receipts from the leasing of fields, from live stock, fisheries, etc., was $2,020,000 and the gross expenditures $1,844,000. From these figures it would appear that there was a profit of $177,200. From this apparent profit there must be deducted the cost of administration for the farms, the cost of new buildings, interest on loans and sinking fund charges, amounting to $1,181,000, leaving a deficit of $843,000.

COLOGNE

The sewage disposal works for Cologne are situated in the suburb of Niehl, about three miles below the city and about 90 miles above the Netherlands. The population is about 540,000 and the volume of sewage 14.5 million gallons per day. At low water



Note:- The darker areas represent the denser populations

FIG. 10—COLOGNE

At the disposal works the sewage is passed through fine screens and then through a basin in which it can be disinfected in case of necessity, the effluent being discharged at the bottom of the river Rhine.

level the Rhine flows at the rate of 17,860 million gallons per 24 hours, so that the rate of dilution is about 1 of sewage to 1,230 of water.

The sewage is passed through grit chambers and screens and can, in case of necessity, be conducted through a settling basin where disinfectants can be applied. The discharge takes place through a submerged outlet about 10 feet beneath the surface of the river.

The feature of greatest interest in connection with the Cologne works is the screening process. There is a coarse screen which catches large floating substances such as rags, paper, straw, etc., with 0.6-inch openings and a fine screen with openings of 0.1 inch to collect the smaller floating material. The velocity through the screen is 0.1 inch per second.

The screen is of the fixed bar type placed at an inclination in the sewage. It is cleaned by steel brushes which travel uninterruptedly from the bottom upward and remove the solid matters collected to a conveyor belt which empties into a car and is pushed to manure pits situated nearby. The screenings are taken away by farmers in the vicinity.

After the sewage is passed through the fine screens, it flows through the settling basins which consist essentially of enlargements of the effluent channel. The rate of flow through the settling basin is 1.5 inches per second.

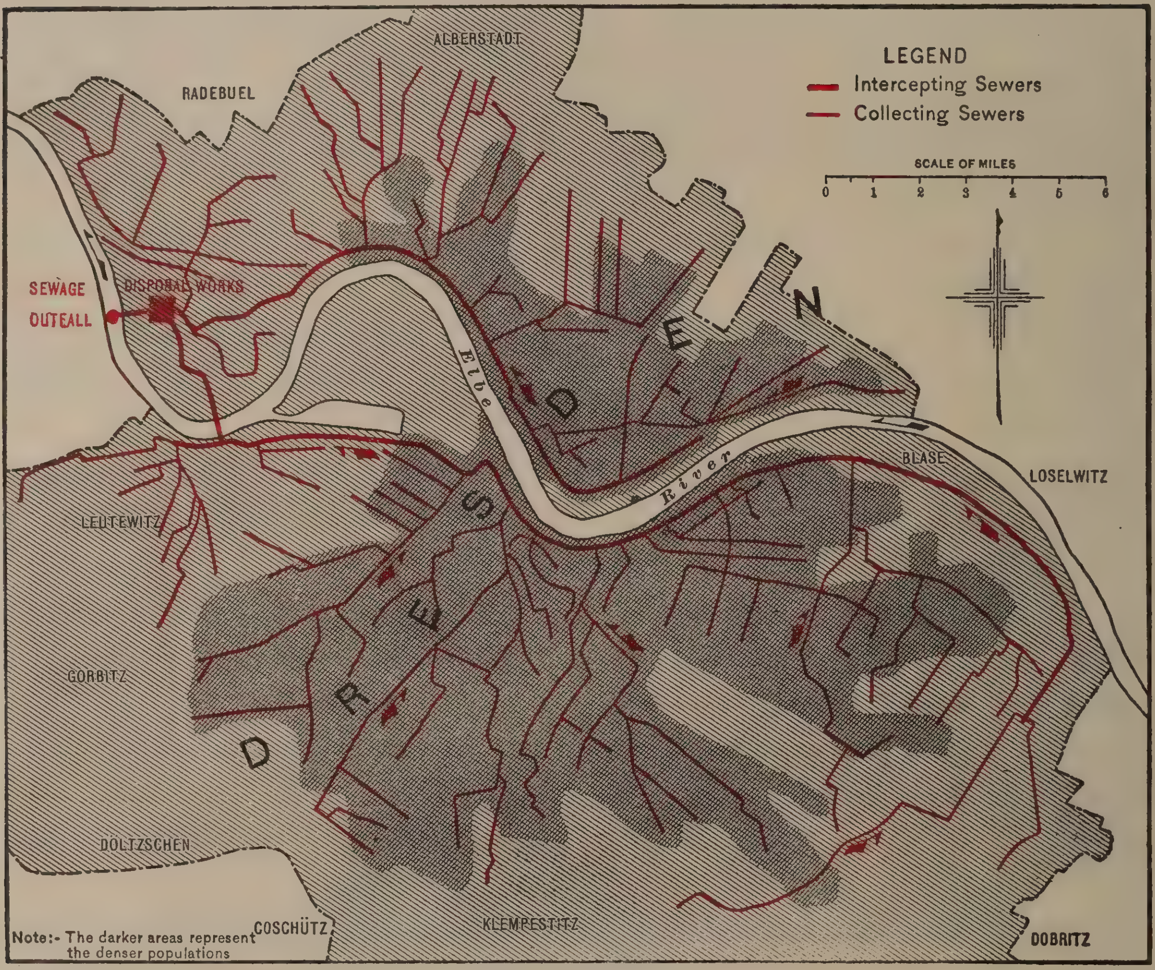
A project has been prepared for the reconstruction of the works. It is intended that the new installation shall have two screens such as are used at Dresden, an enlarged grit chamber, eight sedimentation tanks and twenty sludge-drying beds. The new plant will be built in connection with a refuse destructor, the entire sanitary depot resembling that at Dresden.

Dresden

The city of Dresden, with a population of about 560,000, is situated on the Elbe at a good elevation above the river. The sewers are of the combined type, discharging the excess of storm water to the river by overflows and carrying the dry-weather flow and four to five times this volume of water at periods of storm to treatment works. The dry-weather flow of sewage is about 26 million gallons per day.

The disposal works are situated about three miles below the city and consist of a grit chamber, screens and pumps, the latter being used only at high stages of the river. The usual outlet is situated at the bottom of the river in midstream. During flood stages of the river, when pumping is resorted to, the discharge takes place from outlets at the river bank.

The disposal works include grit chambers, which are cleaned by a bucket elevator, the deposits being utilized for raising the level of low-lying land. After leaving the grit chambers, the sewage passes through coarse screens with openings of about 3 inches. The main purification takes place in Riensch screens, of which four were in operation in 1913. The screen surfaces are metal disks with openings 1.2x0.08 inches in diameter. The disks, whose outside diameter is about 26 feet, are inclined at an angle of about 15 degrees and have about two-thirds of their surfaces submerged.



Note:- The darker areas represent the denser populations

FIG. 11—DRESDEN

The sewage is collected to disposal works where it is passed through fine screens and then discharged at the bottom of the Elbe. The screenings are used for manure.

The cleaning is done by brushes ingeniously arranged to remove the material taken from the sewage. By means of a chute and elevator, the screenings are taken out of the building and disposed of as manure. About 20 to 26 cu. yds. of screenings are produced per day, containing about 80 per cent. of liquid. The Government requires that about 23.4 cu. yds. of sewage solids shall be taken out of the sewage per day before the effluent is discharged into the river.

Each screen has its own intake and outlet controlled by gates and can be used separately, or with the others. A complete revolution of the disk takes place in from 2 to 3 minutes. Each disk contains 230,000 openings. The total area of openings provided is 150,640 sq. ft. for a flow up to 0.14 cu. ft. per second. About 2½ H. P. is required for the operation of each disk. The loss of head produced by the flow of water through the screening disks varies between 2 and 10 inches.

Essen

The river Emscher is a small tributary of the Rhine and the Emscher District covers an area of about 318 square miles, containing a number of cities and towns and a total population in 1913 of about 2,000,000.

The district is low with little natural slope. Unsatisfactory conditions of drainage resulted from the topography and these were made worse by the sinking of the land through mining operations beneath. With the exception of Dortmund, which possessed sewage disposal works, the municipalities in the Emscher District until recently were without satisfactory means either of drainage or sewage disposal.

In 1904 a law was passed to provide for the regulation of the natural drainage and purification of the sewage in the District of the Emscher and authorizing the formation of an association or commission to carry out the necessary works.

Extensive works were undertaken to improve the natural drainage. The sewage, after the removal of as much of the suspended matter as it was practicable to take out by means of settling basins, was discharged into the open water courses.

A new type of settling basin which was invented to treat the sewage is known as the Emscher or Imhoff tank. The Emscher tank consists of two deep settling basins, one within the other. The sewage passes through the inner tank, the suspended matters settling to the bottom and passing through an opening to the larger tank below. Fermentation of the solids takes place in the lower tank, which is cleaned at long intervals and then only to such an extent as is necessary in order to remove the fermented sludge which is ready to be taken out. Large quantities of gas are produced and escape through suitably arranged outlets.

By fermentation, the consistency of the sludge is changed to a state in which it readily and quickly parts with its liquid when placed upon a filter. When drawn from the tanks the fresh sludge contains 75 per cent. of liquid and this, by drying upon coarse filters exposed to clear weather for four or five days, is reduced to 50 or 60 per cent.

The sludge is withdrawn from the tanks without removing the supernatant sewage, a sludge pipe extending from the bottom to the point of outlet which is situated sufficiently below the level of the sewage to provide the necessary hydraulic head.

The fermented sludge is odorless and, after drying, may be used to raise the level of low-lying land. The effluent is discharged into the open water courses in the district, all of which are closely fenced in. The sewage, although putrescible, is not anywhere in an actively fermenting condition. The tanks are sometimes located close to built-up sections of cities and there is said to be no cause for objection. The gases given off consist largely of carbon dioxide and methane, both of which are odorless. The works are uncovered.

The Emscher tanks remove about 90 to 95 per cent. of the suspended matters which are capable of settling from the sewage, the usual period of sedimentation being about two hours.

The sewage is collected through combined sewers from which factory wastes are not excluded.

The drainage board is charged not only with the regulation of the natural drainage and the purification of the sewage, so far as construction is concerned, but it is charged with the duty of operating the works after they are built. The board has the right to acquire land, collect the taxes to pay the interest on the cost of construction and operation and has complete autonomy of administration.

According to the original plans, the work in the Emscher District was to cost $6,750,000, but subsequent estimates have increased this amount to $8,100,000. Of this sum three-quarters had been expended in 1906. It is expected that the sums spent for the purification plants will amount to about $1,665,000, which is about one-half of the total spent by the board for all purposes. Nineteen purification plants were in operation in 1913, with 770,000 inhabitants connected to the tributary sewers. Two additional plants for the sewage of 66,000 inhabitants were expected to be completed in a short time and 7 additional plants for the sewage of 347,000 inhabitants were to be built within a year. The total number of plants in the district anticipated by the end of 1914 would be 28, and these would serve for the sewage of about 1,200,000 inhabitants.

FRANKFORT

The works at Frankfort are situated on the banks of the river Main, three miles in a direct line from the Cathedral, which may be taken as the center of the city. The population is about 400,000. The dry-weather flow of sewage is about 58 gallons per capita, or about 24 million gallons per 24 hours. The capacity of the works is six times the dry-weather flow.

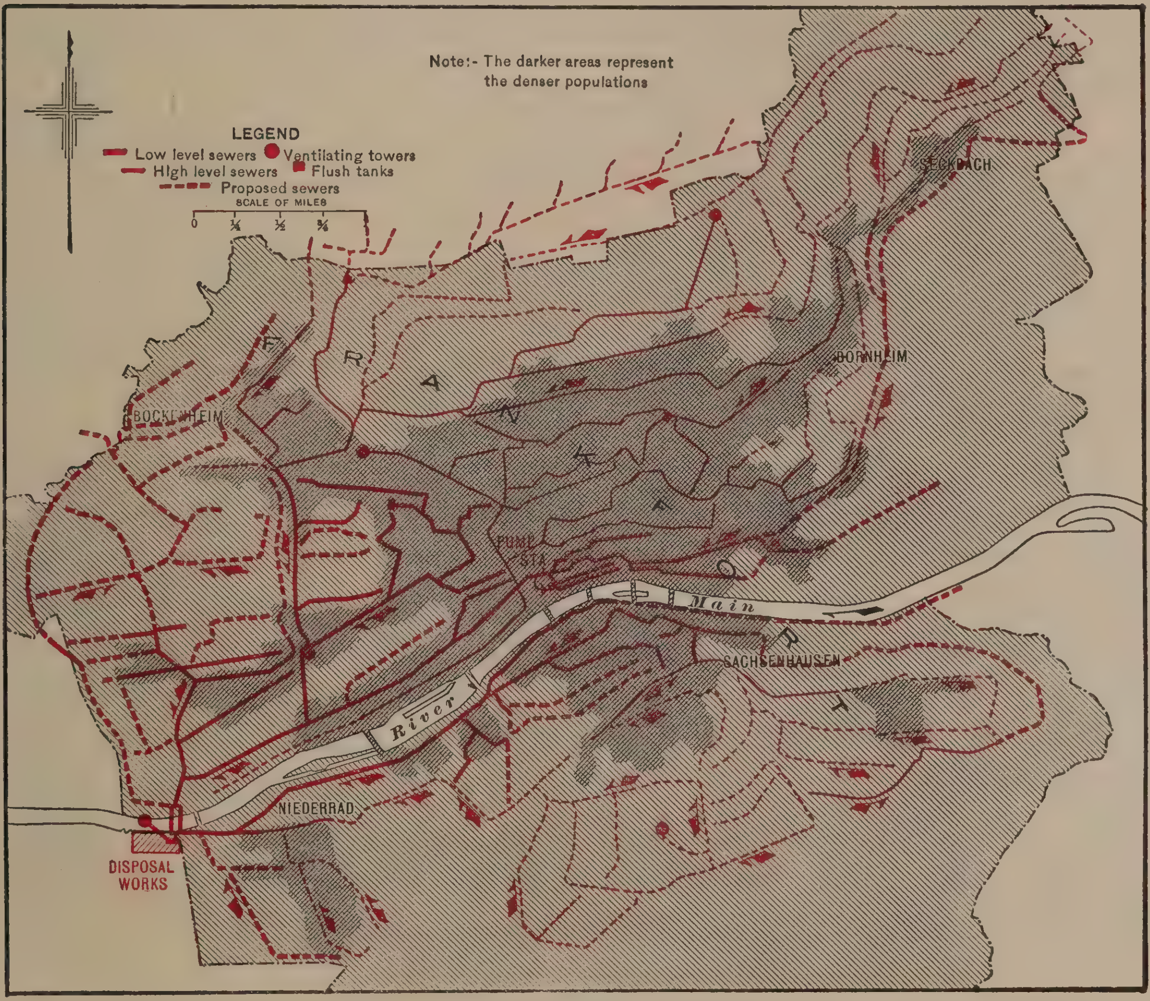


FIG. 12—FRANKFORT

The sewage is collected to a central depot (where garbage is also disposed of) and is passed through fine screens and settling basins before being discharged at the bottom of the river Main. The screenings and sludge after drying are burnt in the garbage destructor.

The river at the works is less than 500 feet wide and is a rather turbid, navigable stream with a rapid current. The amount of dilution at low stages is about 1 part of sewage to 130 parts of water. At average stages, this ratio is 1 to 300 and at high water about 1 to 1700. During flood stages of the river, the effluent from the works has to be pumped.

Three essential features connected with the Frankfort works deserve to be mentioned: The rotary screens, the settling basins and the treatment of the sludge. The sewage is passed through grit chambers which are cleaned by dipper dredges discharging through a chute. The grit is transported a short distance by cars to be finally dumped upon land. The screens consist of horizontally-placed wheels with five sets of vanes with spokes three-eighths of an inch apart, which revolve in the sewage like an undershot water-wheel only against, and not with, the current. The sewage flows between the bars, leaving the suspended matter caught on the revolving screen. The rakes revolve once in about 2½ minutes.

The solids removed by the screens are scraped from the vanes by an automatic cleaning device which delivers them to a traveling belt. The screenings are pressed by hydraulic power and burnt in a nearby refuse destructor.

The settling basins are fourteen in number and are shaped somewhat like the hull of a ship. They are provided with scum boards to hold back the grease. Care has been taken to so incline the bottom that the sludge will flow to the outlet with little or no hand assistance. The basins are lined with glazed tile.

When the settling basins are cleaned, the sludge is pumped by means of compressed air to overhead reservoirs from which it feeds by gravity to the centrifugal driers, a short distance away. These machines which revolve at great velocity upon horizontal axes receive a constant supply of sludge and yield a partly dried sludge and an offensive liquid. The moisture content is reduced from about 90 to about 60 per cent. There are eight machines with a capacity of 3.9 cubic yds. per hour each. The sludge which emerges from the centrifugal machines passes through long cylindrical rotary driers heated to about 572 degrees Fahrenheit where the moisture content is reduced to about 20 per cent. The sludge is finally burned.

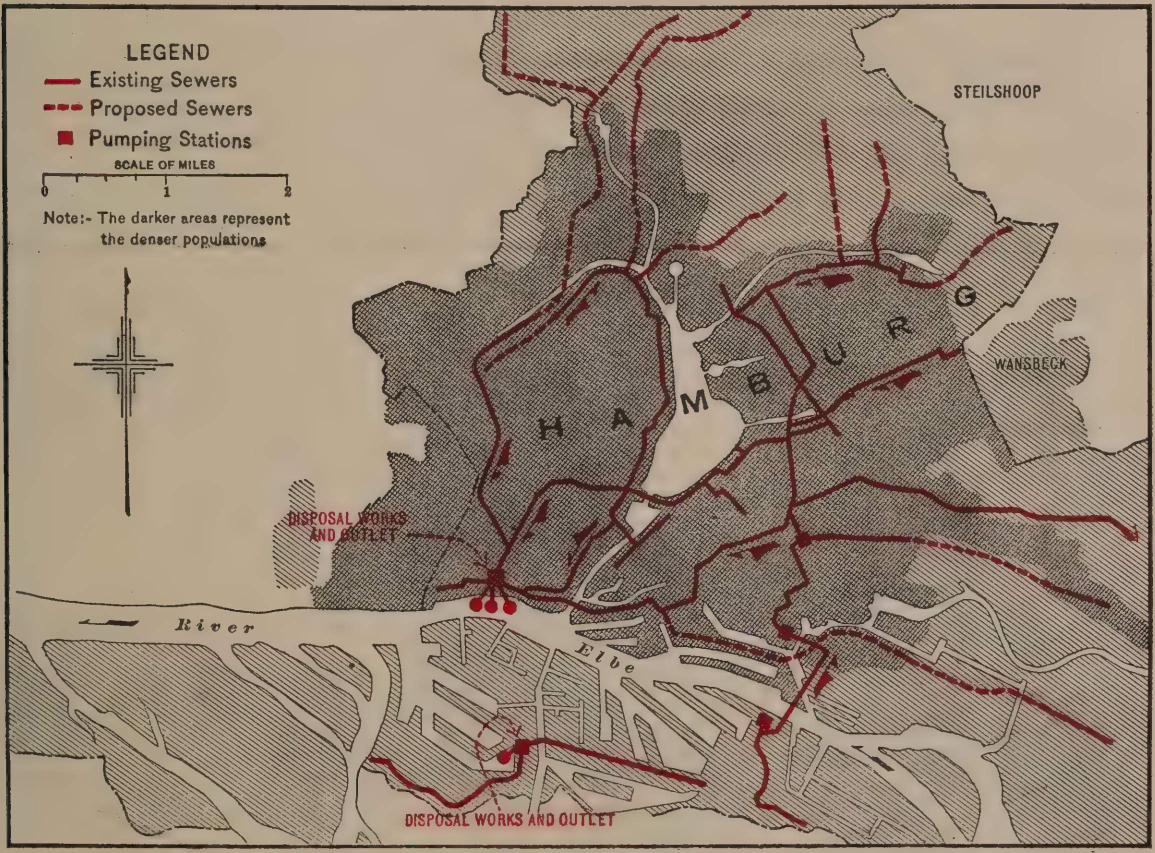
The works reduce the suspended matter in the sewage from about 500 to 100 parts per million, of which about 65 per cent. is removed by sedimentation.

HAMBURG

Hamburg, although termed a seaport, is situated on the river Elbe, 65 miles from the ocean. Much of the land is low. The Elbe flows through several channels at this point and is joined by other and smaller rivers. The water is turbid, especially after rains.

The sewage is collected in a combined system of sewerage, the dry-weather flow being conveyed to the main treatment works and outlets and the storm flow being discharged by overflows into the canals which intersect the city in many directions. The population is about 960,000 and the volume of sewage discharged through the outfall works amounts to about 115 million gallons per day.

Although unfavorably situated for drainage, Hamburg is one of the most completely and efficiently sewered cities in Europe. In accordance with a comprehensive drainage plan, the sewage is carried to two principal points for treatment and discharge. The treatment consists in passing the sewage through grit chambers and screens. It is then allowed to empty into the Elbe through submerged outlets.


LEGEND
Existing Sewers
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Pumping Stations
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Note:- The darker areas represent the denser populations
STEILSHOOP
WANSBECK
HAMBURG
DISPOSAL WORKS AND OUTLET
River
Elbe
DISPOSAL WORKS AND OUTLET

FIG. 13—HAMBURG

Large grit chambers and fine screens are employed at the two disposal stations at Hamburg, the solid material removed being carried away by boats to farm lands.

The screens are of the endless belt type and are cleaned by automatic rakes which remove the screenings to a short belt conveyor which empties the material into cars. The cars are pushed by hand a short distance to chutes which discharge into barges. The screenings are used by farmers. The space between the bars at the older and larger screen station is 0.6 inch. The new screens have spaces of 0.4 inch.

The range of tide at Hamburg is 6.2 feet. The outlets of the works are closed at high stages of tide and opened again when the tidal level falls.

The older and larger grit chamber and screening station is covered by an ornamental brick building and is situated in the built-up portion of Hamburg close to the city of Altona which immediately adjoins it. There is no nuisance from odor in the vicinity of the works. By close inspection of the river, solid particles, recognizable as of sewage origin, can be seen rising to the surface of the river and at certain seasons the presence of gulls indicates where the outlets are located. The canals and waterways of the city are attractively clean.

COPENHAGEN

Copenhagen is situated on the east coast of Sealand, the largest part of the town being built on the main island, while the suburbs "Christianshavn" and "Sundby" occupy the north end of the island "Amager" (Amak). The narrow water between Amager and Sealand has in course of time been converted into the harbor of Copen-

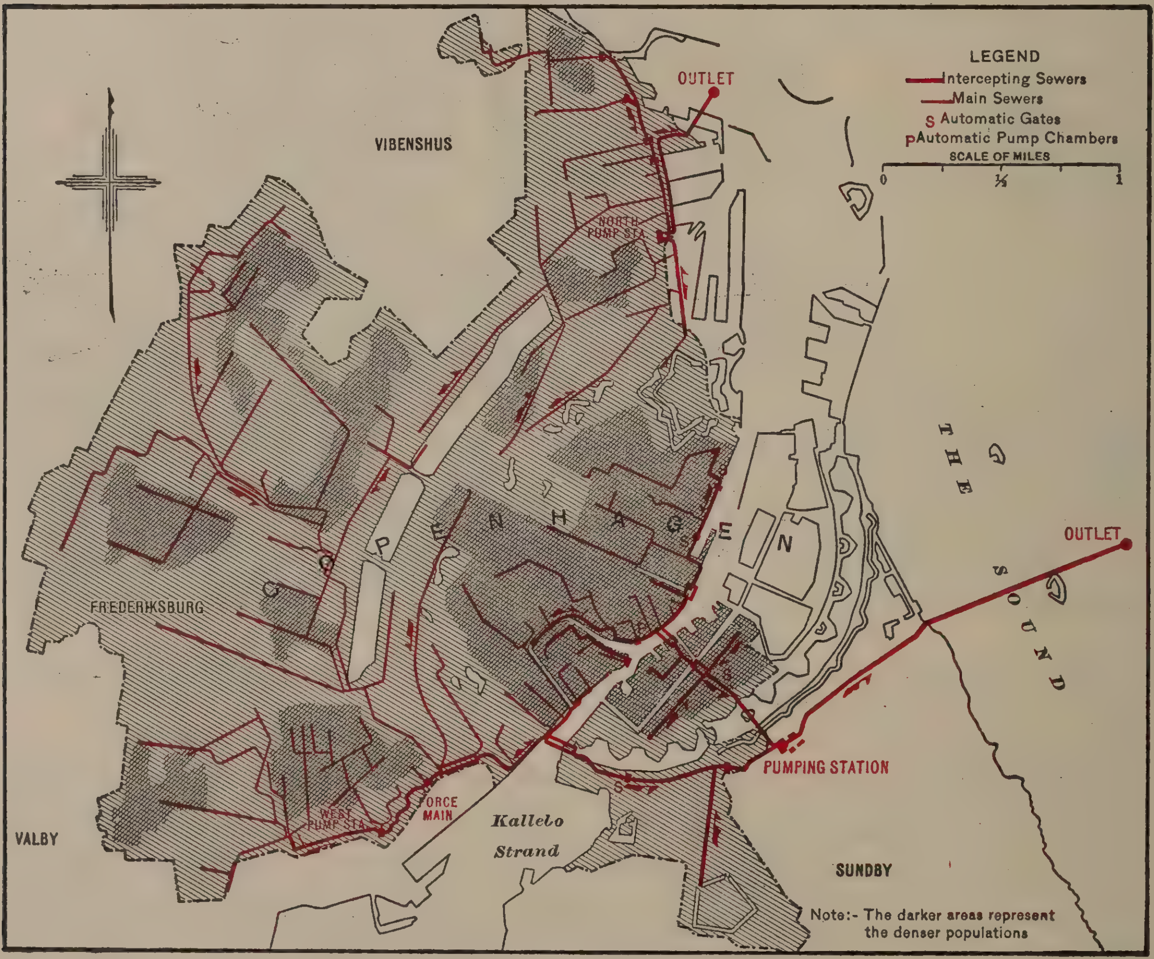


FIG. 14—COPENHAGEN

Two main outlets are provided for the discharge of the sewage at sea, the principal one being about a mile from shore.

hagen. The east coast of Amager faces that part of the Sound which is called "Kongedybet" (the Kings Deeps) and is the main traffic route, with water depths from 30 to 40 feet. To a distance of more than 3,000 feet from the shore, however, the water is very shallow. There is no tide in the Sound, but according to the influence of the wind the water occasionally rises to 4 feet above or falls to 3 feet below mean sea level. These differences in the water level cause almost constant currents running through the Kings Deep in alternating directions. They also cause currents, though somewhat weaker, through the main harbor.

From ancient times the sewage of Copenhagen was led to the harbor in open channels along the streets and it was not until the middle of the past century that a project for main drainage was taken under consideration.

The first sewers were on the combined plan, and the connection of waterclosets was forbidden by law. Nevertheless, the harbor became grossly polluted and a general nuisance resulted.

About 1890 it was resolved to build a system of intercepting sewers and pumping stations (after the plans of the former Chief City Engineer, Mr. Ambt) in order to intercept the sewage and pump it to an outfall in the Kings Deep and in this way better the conditions so that waterclosets could be connected, which at that time was generally demanded by public opinion. A part of the works were executed in 1892, but the bulk of it was not taken in hand before 1897. It was completed in 1901. The population was 476,806 at this time.

The works are shown on the map, and as will be seen there are three pumping stations: The main station ("Hovedkloakpumpestation") at Klevermarkevej on Amager, and two substations, one ("Nordre Kloakpumpestation") near the free harbor in the northern part of the town, and another ("Vestre Kloakpumpestation") at Vesterbro in the southwestern part.

The sewage flows by gravity to the pumping stations, in intercepting sewers, shown on the map by red lines. They are laid as near the harbor as possible. There are two intercepting sewer mains leading to the main pumping station, one from the center of the town, the other from the southwestern part. Both of these cross the harbor in inverted siphons, the southern one of which is made of steel riveted pipes laid in a trench at the bottom of the harbor and protected by cement mortar, while the northern one is made of cast-iron pipes laid in a tunnel under the harbor.

The intercepting sewer mains are from 2½ to 6 ft. in diameter. At the pumping station the bottoms of the sewers are about 13 ft. below mean sea level. From this depth the water is pumped to the outfall through a double force main, the land section of which is of cast-iron pipe, while the part under the sea is of wood stave pipe.

The two substations have their own systems of intercepting sewers. From these stations the sewage is pumped through force mains, shown on the map in red lines, to the nearest point on the main intercepting sewers, from whence it flows by gravity to the main pumping station and is pumped once more to the outlet.

The intercepting sewers and pumping stations are constructed to receive and deal with twice the maximum dry-weather flow. When during rains the flow exceeds this quantity, the surplus goes directly into the harbor through storm overflows.

The outlet is situated nearly one English mile from the shore at a point where there is 33 feet of water at mean sea level. The total distance from the pumping station to the outlet is 9,200 feet. The outfall section is built of wood staves which are kept together by wooden ties or hoops. They are laid down in a trench in the bottom of the sea and covered with 3 feet of sand filling. The outlets are made by opening the pipes at the top and building two timber walls up to a foot above the bottom. Each pipe has an opening 27 feet long and 6 inches wide, causing the sewage to discharge in a thin sheet, which is easily caught by the current and diffused with the sea water. There are almost constant currents through the Kings Deep with an average velocity of nearly one mile an hour. As compared with the tidal currents ordinarily encountered on the English Coast, these currents have the advantage of running for several days in the same direction and therefore will take the sewage to such a distance that there is no danger of its returning when the current changes. The outlet has now been in use for several years without causing the slightest nuisance.

VIENNA

Vienna is situated on the left bank of the Danube, which is here about 1,000 ft. wide, and in 1911 had a population of 2,004,000. The river has an average volume of flow of about 27,750 million gallons per day. A part of the city is situated on an island formed by the Little Danube. Although intercepted with water-courses, the natural drainage is relatively good.

The sewage is collected upon the combined plan. There is much drainage from uplands lying to the west which is carried through the city by means of large culverts. Many combined sewers emptying directly into the Danube or Little Danube have been intercepted by large sewers along the banks and now discharge into the Little Danube below the city. It is intended to extend the works in order that they may discharge into the main stream at a more distant point after screening. The dry weather flow of sewage is 24 gallons per capita per 24 hours and the sewerage works are designed on the theory that one-half of the total quantity will flow off in 10 hours.

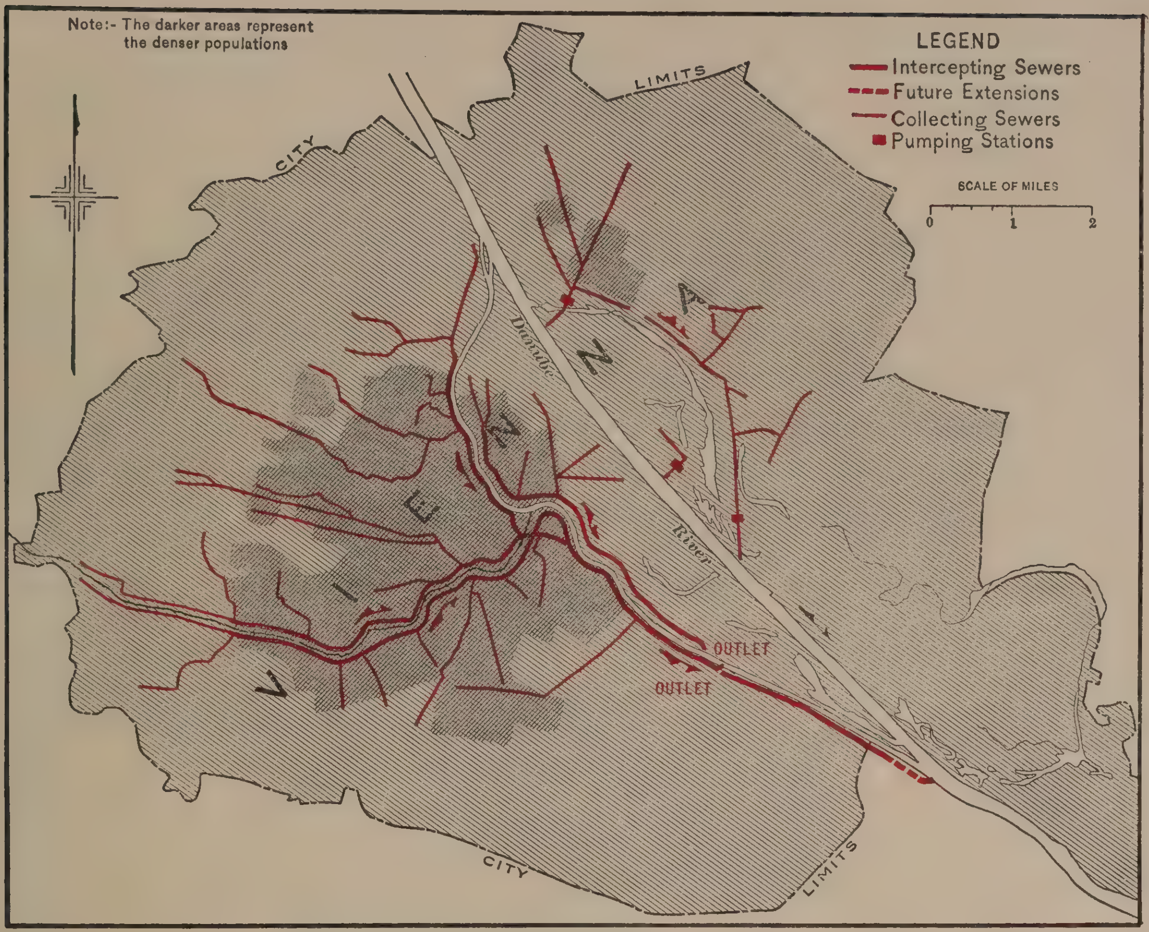


FIG. 15—VIENNA

The sewage is collected by interceptors running parallel to the banks of the water-courses, and discharged through one main outlet into the Danube after passing through grit chambers. The large flow of this stream is favorable to disposal by dilution and renders further treatment unnecessary. No nuisance is produced.

In extensions of the sewerage system now being planned preparation is made for the drainage of a population of about 5,000,000, which it is expected will be present if the recent rate of increase continues.

At the present time the sewage from a population of 1,400,000 is carried to the Little Danube outlet. There is one main outlet, the flow being 49.4 cu. ft. per second in dry weather or 32 million gallons per day. Numerous storm overflows exist on the Little Danube.

Grit chambers are placed upon the main tributaries of the principal intercepting sewers. These grit chambers are of sufficient size to reduce the velocity sufficiently to permit sand to settle out. There are twelve of these chambers and from them 39,200 cu. yds. of grit are removed each year.

The large volume of water flowing in the Danube and the high rate of flow, averaging about 6 ft. per second, are favorable to the disposal of the sewage through dilution. The water within the city is without visible pollution. It is said that after the river has flowed about 25 miles beyond the city there is no trace of sewage pollution.

PARIS

Paris affords a good example of a city of the first class which protects its water highways by a comprehensive plan of main drainage. Except at periods of storm, no sewage is allowed to enter the river Seine within the city limits. In consequence, the Seine within the city limits is a remarkably clean and wholesome looking stream.

How difficult the accomplishment of this thorough protection has been may be understood from the fact that the river winds through the center of Paris, is a navigable stream and supports a large commerce.

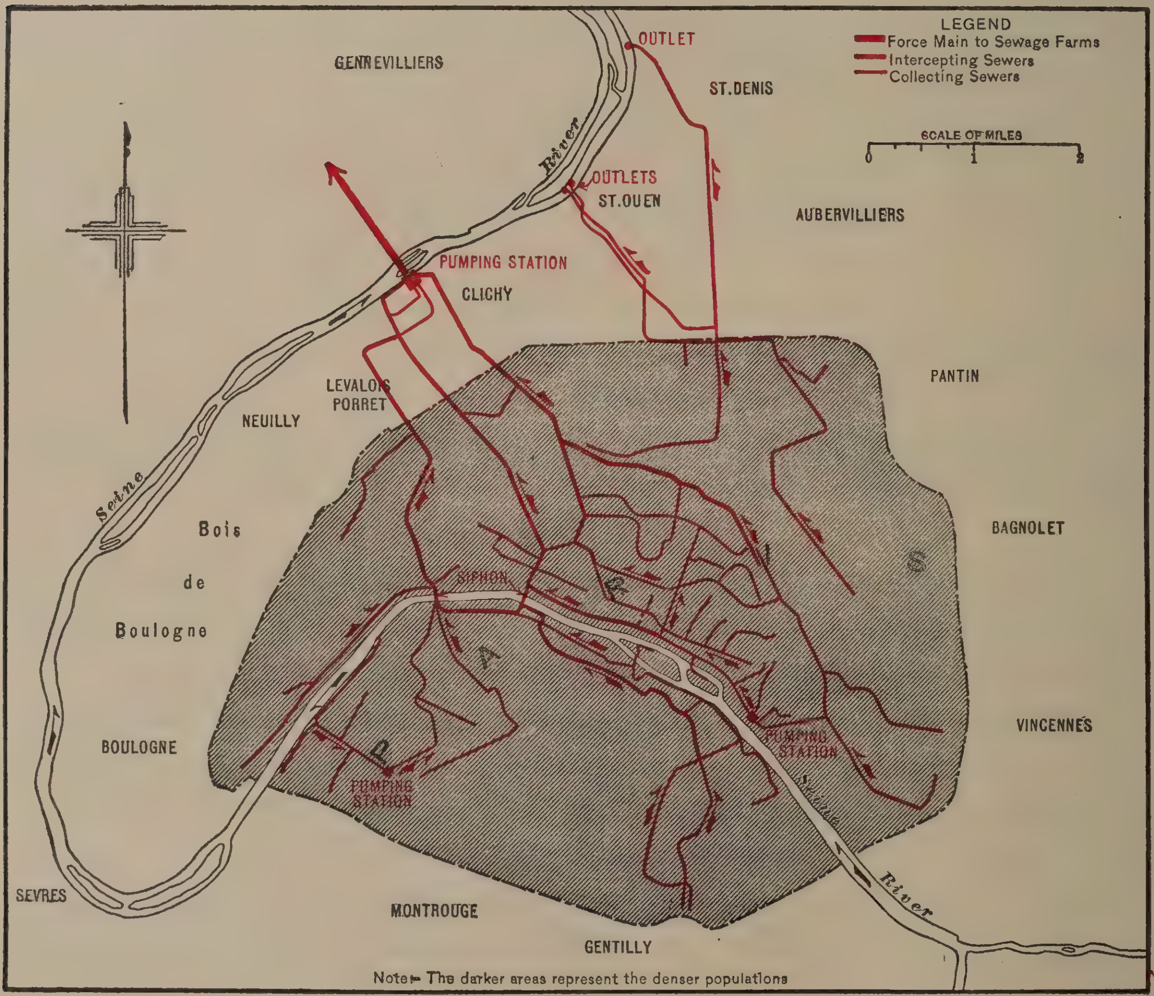


FIG. 16—PARIS

Most of the sewage of Paris is conveyed to Clichy, where it is passed through a grit chamber and screens and pumped to extensive farm lands.

The sewers of Paris are intended to accommodate the sewage of houses and streets and all the solid matter which can well be flushed into them from the street pavements. There are no catch-basins, in consequence of which sand, paper, fragments of wood and much other coarse debris from the sidewalks and carriageways enter the sewers and must there be dealt with. The streets are washed and the gutters flushed continually. Unlike the usual custom of flushing sewers by means of suddenly released reservoirs of clean water, the sewers of Paris are flushed with their own sewage. This is accomplished by setting a movable dam in the sewers which causes the sewage to accumulate temporarily until there is a considerable force behind the dam. The dam is then allowed to move slowly toward the outlet of the sewer. An open space between the dam and the invert provides an outlet for the sewage, which flows away with a scouring action sufficient to dislodge whatever accumulations of solids may exist.

The siphons which carry sewage from one part of the city to another beneath the river are kept clean by passing wooden balls through them. These balls are slightly smaller than the siphons and their passage causes a desirable scouring action. The solid matters are flushed to certain parts of the sewerage system, where provision in the form of grit chambers exist for their removal. This solid material is removed by means of grit chambers, emptied into cars which are wheeled to the river bank and there discharged into barges.

The main drainage works are designed to focus at Clichy on the Seine, a considerable distance beyond the city limits. Most of the sewage flows to this point by gravity through three large collectors. Pumping stations in some parts of the city raise a part of the sewage from low-lying areas into the gravity system. Intercepting sewers run parallel to the river banks within the city limits and are tributary to the main sewers which lead to the Clichy station. Some of the sewage in the northern part of the city is carried to outfalls into the Seine at St. Denis and St. Ouen, points considerably below Clichy.

The sewage of Paris, except that discharged into the Seine at and below Clichy, is utilized upon farm land. The history of the Paris disposal works is of much interest. Before irrigation was adopted various other methods were tried for the disposal of the sewage. A scheme for taking it to Havre is said to have been prepared, but was found impracticable by reason of excessive cost.

It was at first supposed that the sewage could be sufficiently relieved of its impurities by sedimentation before the effluent was discharged into the Seine. Sedimentation was therefore attempted at Clichy, but soon proved to be inadequate, the river becoming black and offensive. Deposits of sludge occurred which, decomposing, caused bubbles several feet in diameter to rise to the surface and burst, leaving large quantities of black mud to return slowly to the bottom or become diffused through the water. It is estimated that there were 107,000 cubic yards of sludge taken from the stream each year. With the object of improving the efficacy of purification, chemical precipitation was then used, sulphate of alumina and lime being the reagents. The result was greatly to increase the quantity of sludge without making a sufficient improvement in the effluent.

In 1867 and 1868 irrigation was first tried on a small experimental plot at Clichy and this proved so successful that in 1869 the city offered to supply sewage gratis to anyone who would use it at Gennevilliers.

At that time Gennevilliers, which is situated on the opposite side of the river from Clichy, was a small and obscure place devoid of agriculture. Irrigation proved so successful that whereas in 1870 there were 55 acres under cultivation, by 1875, 314 acres were treated with sewage.

The Paris plant now consists of four large areas, the oldest at Gennevilliers. Plants of more recent origin are situated at Acheres, Pierrelaye and Carrieres and Triel. The total area of the four districts amounts to about 13,597 acres, about one-third of which is owned by the city. At Gennevilliers the land is privately owned and the city maintains a model experimental garden for the cultivation of fruits and flowers. Among the crops grown are peas, tomatoes, grass, etc.; large tracts are also used for pasturage. The cultivation of strawberries, salad crops and other food exposed to sewage and eaten raw is prohibited.

About 185 million gallons of sewage per day are produced at Paris. Of this amount about 159 million gallons are screened at Clichy, the screenings amounting to about 77,000 lbs., and then pumped to the irrigation fields. The distance from Clichy to Carrieres-Triel is about 17.36 miles. The sewage is pumped from Clichy to Colombes against a head of 16 feet. At Colombes 126,000,000 gallons are repumped with a lift of 118 feet, the remainder being diverted to Gennevilliers. At Pierrelaye, a part of this is repumped with a lift of 83 feet, the remaining volume continuing by gravity to Acheres and Carrieres-Triel. The population of Paris was 2,846,986 in 1911.

The sewage is delivered to the fields in closed conduits and distributed in ditches.

BIRMINGHAM

Birmingham, with a population of 850,000, stands on high, undulating land in the center of England and is situated within a few miles of the headwaters of the river Tame which, although but a few yards wide, receives the drainage of Birmingham and a number of other municipalities in the vicinity. The average flow of the river is

28,800,000 U. S. gallons per day, which is less than the quantity of sewage which must be emptied into it.

The disposal of the sewage of Birmingham and its neighboring towns is carried on under the joint management of a drainage district which covers over 100 square miles and has a population of about 950,000. The managing authority, known as the Birmingham, Tame and Rea District Drainage Board, was created in 1877. The disposal works occupy a tract of about 3,000 acres which runs for six miles through the Tame valley at a short distance from Birmingham. The works are divided into parts, some of which are widely separated. Most of the sewage is passed through grit chambers, septic tanks, settling basins, sprinkling filters and again through settling basins. The effluent is as pure as the river water into which it is discharged.

The process of sewage treatment is remarkable for the repeated efforts which are made to remove solid matter in suspension and for the ingenuity which has been shown in adapting advanced methods of sewage purification to the peculiarities of the local situation.

The original works constructed in 1895 comprised chemical precipitation tanks and about 80 acres of land for irrigation. The purification effected was not satisfactory and numerous experiments were made to improve the effectiveness of the plant. It is said that 454 patented processes were experimented with.

At one time the Birmingham disposal works consisted of the largest 'farms' in England used for the disposal of sewage. The farms were capable of dealing with 7,200 gallons per acre per day, or about 14,400,000 gallons for the whole area capable of receiving sewage. Notwithstanding this, the land was frequently called upon to deal with 24,000,000 gallons per day, with the result that the effluent deteriorated and the land became sodden. The cultivation of crops was then given up and the fields were alternately flooded and drained on the principle of intermittent filtration. This proved a failure and works were constructed on the principle of biological purification.

Since 1911, sprinkling filters have dealt with the dry-weather flow of sewage and a large amount of storm water as well. The sewage which arrives at the works first passes through grit chambers through which the sewage flows at the rate of 3 inches per second. The deposits are removed by dredging and carried away by wagons by an industrial railway to land where the material is buried. It is considered better not to attempt to sell or utilize this solid material because of the nuisance likely to result and its small manurial value, consisting chiefly of about 2½ per cent. of nitrogen and about 1¼ per cent. of phosphoric acid.

On passing through the grit chambers, the sewage flows through septic tanks where solid matter is deposited and fermentation allowed to proceed. The septic tanks, of which there are 20, are divided into two groups called primary and secondary. The sewage flows through both groups, then passes over a distance of five miles to settling basins known as silt tanks and thence upon sprinkling filters. These filters consist of broken stone 6 or 7 feet deep and of areas between 1 and 3 acres each, the total area being 37 acres. The average rate of filtration is about 900,000 U. S. gallons per acre per day. After passing through the bacteria beds, the sewage flows to settling tanks where solid matters in suspension are removed before the effluent is allowed to enter the river Tame.

The total amount of suspended matter in the crude sewage, as determined from the average of analyses of half-hourly samples taken every day during the year 1908, amounted to 522 parts per million. During that year the total quantity of sewage treated was about 14,400,000,000 gallons, which gives 24,300 tons of dry matter disposed of in that year. Of this total, 17 per cent. was removed in the grit chambers; 23 per cent. was taken out in the septic tanks and from them pumped in the form of sludge to fields, where it was allowed to settle and dry sufficiently to be ploughed into the soil. The silt tanks removed 18.1 per cent., these solids being pumped to the sludge fields and dried like the solid matter from the septic tanks. The quantity of solids removed in the separatory tanks which received the sewage after it had left the sprinkling filters was 11.7 per cent. This material was also pumped to the sludge grounds. About 8.5 per cent. was deposited in the piping system and was flushed out and pumped to the sludge fields and 9.7 per cent. was deposited on land where some of the sewage was used for irrigation. During storms 8.2 per cent. passed by overflows to the river. The effluent which went from the purification works to the river contained 3.6 per cent.

Contrary to general experience, the sludge produced at Birmingham has been practically without odor, a fact which has been accounted for on the ground that a large amount of trade waste is present containing copper and iron, which interfere with those bacterial growths which produce foul-smelling gases.

GLASGOW

Prior to 1894 the sewage of Glasgow was discharged without purification into the river Clyde. The evils which resulted from this practice were comparable with those which once obtained on the Thames at London.

The territory included in the Glasgow main drainage project extends along both sides of the river for about 15 miles, the total area being 41½ square miles. It is expected that the ultimate development will yield a total volume of sewage, including rainfall, of 300 million gallons per day. The drainage area is divided into three parts, each tributary to a central collecting station where the precipitation works have been constructed. The population was 735,906 in 1901.

The first section drains the combined sewage of about 11 square miles, one-half of which is within the city limits, to the works situated at Dalmarnock. These works have been in operation since May, 1894, and deal with about 24 million gallons per day.

The second section comprises that part of the municipal area of Glasgow which lies on the north side of the river westward of the first section and some outside territory, the whole area being about 15 square miles. These disposal works are at Dalmuir on the river banks about 8 miles below Glasgow. The daily volume of sewage to be treated ultimately is 58.6 million gallons.

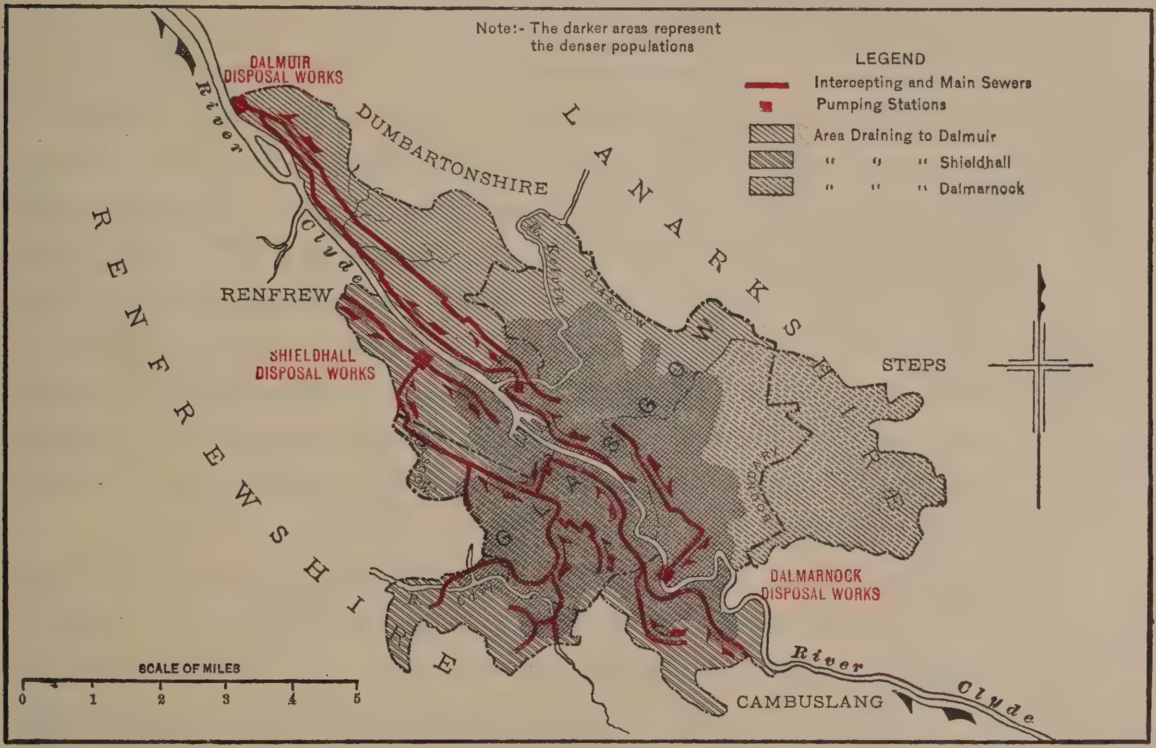


FIG. 17—GLASGOW

The sewage is collected to three central points, where it is passed through chemical precipitation works and the effluent discharged into the river Clyde. At two of the works, the sludge is put on board of tank steamers which carry it to sea. At the other works the sludge is converted into fertilizer.

The third section includes the whole municipal area of Glasgow which lies on the south bank of the river and some outlying territory, the total area being 15½ square miles. These disposal works are at Shieldhall, 4½ miles below Glasgow. The daily volume of sewage ultimately provided for is 58.6 million gallons.

The sewers tributary to the Glasgow works, like most sewers of Great Britain, were designed to carry both domestic and industrial sewage and a certain proportion of the rainfall. The allowance for rainfall is one-quarter of an inch in 24 hours. Rain water, in excess of that allowed for, passes through regulating valves placed between the street drains and the main sewers and so flows to the river. Tide gates, consisting of balanced flaps, are intended to prevent the river water from entering the sewers during ordinary conditions of weather. The action of these automatic tide gates is said to be satisfactory.

On arriving at Dalmuir the sewage is passed through a screen and flows thence to a grit chamber which is cleaned by a bucket dredger which travels to and fro on tracks over the top of the basin. The precipitating chemicals are then added, and the sewage flows into one or other of eight precipitation tanks, each 750 feet long by about 80 feet broad, situated on the river bank at a level of about 4½ feet above high tide.

The chemicals employed are persulphate of iron and lime water. A saturated solution of lime water is used as a precipitant. This is said to be an advantage over the custom of using milk of lime, which introduces a considerable amount of suspended matter into the precipitation basins. The iron is purchased in the form of ferrous sulphate. It is dissolved in tanks at a temperature of 100 degrees Fahr., protosulphate of iron being then produced. The liquor from the tanks is raised by a pump to an overhead storage tank from which it is drawn from time to time into oxidizer drums. These drums are made of wood, 12 feet long and 12 feet in diameter. They receive a charge of protosulphate of iron and a small quantity of nitrate of soda. The drums are then closed and paddles are set in motion which agitate the contents. At the end of three-quarters of an hour or so, the liquor, now persulphate of iron, is run off in vats below the drums and is ready for use.

During the year ending May 31, 1913, the sludge steamer *Dalmuir* made 271 trips at a cost of $0.05 per ton of sludge. The sludge contained 86.16 per cent. of moisture. There were produced 22.9 tons of crude sludge per million gallons of sewage. The quantity of material removed from the sewage by screens and grit chambers was 6 cwt. per million gallons. At Dalmarnock the sludge produced was 44.4 tons per million gallons. The average moisture was 98 per cent. There were treated at the three works 117.9 million gallons of sewage per day.

The effluent from the tanks flows into a wide channel and, after passing over a gauge weir, is discharged into the river by means of pipes which are protected from the back flow of the tide by balanced tide flaps.

To remove the sludge, each precipitation tank is emptied in succession, the sludge being drained into a sludge well from which it is pumped into an overhead storage tank. After a brief period of settlement, the sludge is allowed to flow into a steamer with a capacity of about 1,200 tons of sludge. The steamer carries the sludge to a point about 45 miles from Dalmuir in the Firth of Clyde, where the sludge is discharged in about 10 minutes into water 60 to 90 fathoms deep.

The method of sludge disposal at Shieldhall is practically the same as at Dalmuir. The works at Dalmarnock treat the sewage in the same way as it is treated at Dalmuir and Shieldhall, but the sludge is pressed for the reason that the river Clyde is not of sufficient depth at Dalmarnock to accommodate a sludge steamer of the requisite size.

The sewage at Dalmarnock consists largely of industrial refuse, the suspended matter varying from 285 to 14,240 parts per million. It is claimed that the treatment eliminates the suspended matter and effects a chemical purification of 50 per cent. calculated on the albuminoid basis. After treatment the sewage is discharged into the Clyde which, at Dalmarnock, has a volume 50 times greater than the average volume of sewage discharged.

Further down the river at Shieldhall and Dalmuir, the 115 million gallons of sewage which is discharged is diluted with about 3,600 million gallons of water. It is assumed that the natural agencies in the river effect the final purification of the effluent, more especially in the lower regions.

The cost of the Glasgow main drainage undertaking exceeds $10,000,000. It is said that the increased rate of taxation due to this expenditure has raised no objection on the part of the public. The undertaking has removed from the Clyde the solid matters of the sewage of Glasgow and adjacent boroughs and has restored what has been termed a dead river at certain period of the year to a live and satisfactory condition.

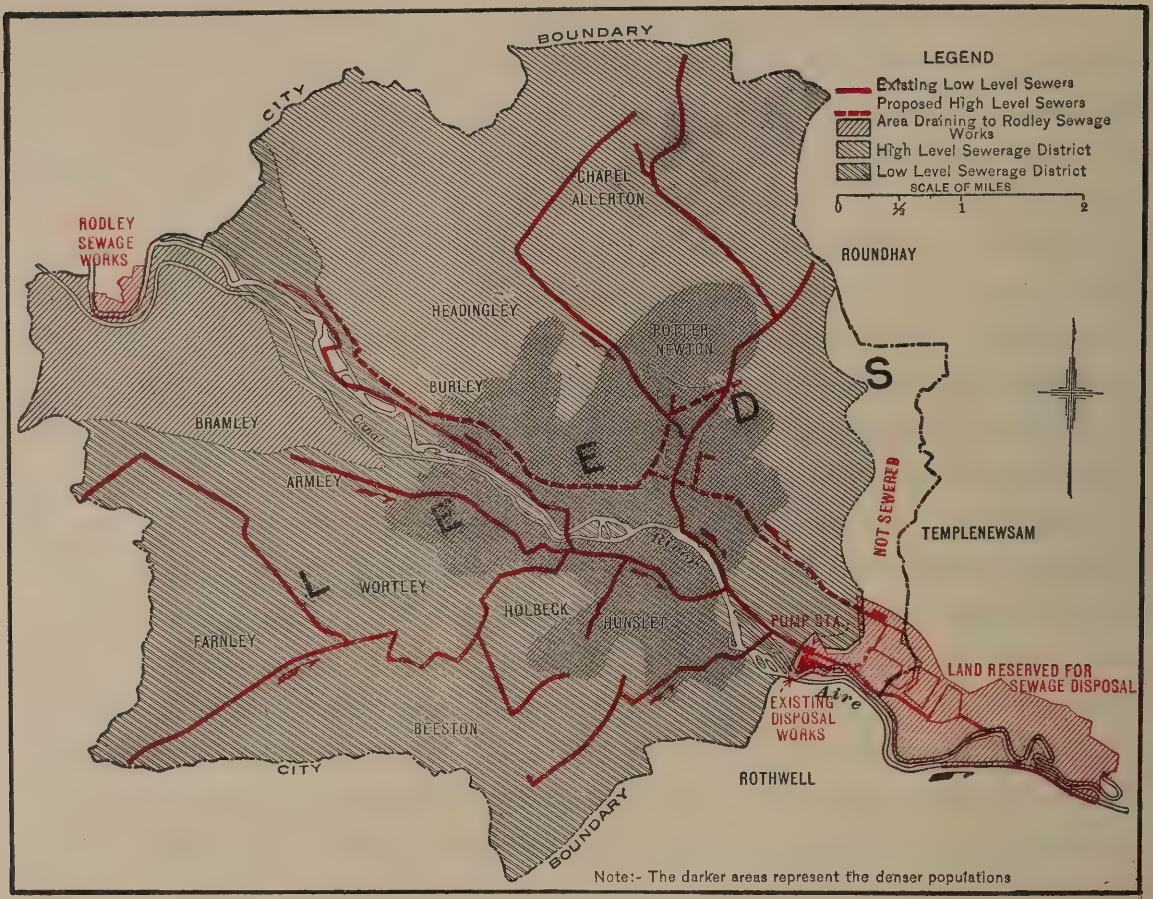
LEEDS

The sewage of Leeds contains a large amount of suspended solids, averaging in the year ending March 31, 1913, 604 parts per million. The soluble solids amounted to 1,010 parts and the albuminoid ammonia to 7.69 parts. In the year mentioned, the suspended solids in the effluent from the works which is discharged into the River Aire were 44 parts per million, the soluble solids 1,001 parts and the albuminoid ammonia 4.8 parts.

The main drainage system was begun in 1848 and the city has been in legal difficulty from the pollution of the Aire since 1870. Experimental methods of disposal were early tried and, in 1874, settling tanks and chemical precipitation were undertaken. The method employed in 1913 was chemical precipitation, but this method did not produce an effluent which was considered satisfactory.

The works for Leeds are situated at Knostrop on the River Aire near the southeast boundary of the city at a distance of 2 miles from the Leeds town hall. The population which drained to Knostrop in 1912 was 435,845.

One of the first things done by the West Riding of Yorkshire Rivers Board when



Note:- The darker areas represent the denser populations

FIG. 18—LEEDS

The sewage is conveyed to a central point beyond the city limits, where it is treated by chemical precipitation and the sludge dried by filter presses. A large area of land has been procured in order to provide for a more efficient process of disposal before the sewage is discharged into the river Aire.

it came into existence in 1893 was to bring pressure to bear upon the Corporation of Leeds to deal with its sewage in an adequate manner. Soon after this, the works were increased in capacity and experiments were undertaken on biological treatment. The land available for the works was inadequate for material improvements and it was not until 1908 that 600 acres were purchased in the vicinity of Knostrop and the city is now going forward with the construction of needed improvements and extensions.

The experiments made by Leeds between 1898 and 1905 left little to be desired for thoroughness and comprehensiveness. As a result, it was decided that the process to be employed should be chemical precipitation followed by treatment with sprinkling filters, with possible subsequent settlement in humus tanks. This process seemed likely to most completely satisfy the local requirements of site, quality of the sewage and the demands of the Local Government Board and West Riding of Yorkshire Rivers Board with respect to the quality of the effluent. This process also possessed the following advantages: Small area required for settling tanks; the sludge would be easy to press with a small addition of lime; the danger of nuisance from smell would be reduced to a minimum because the process being rapid, putrefactive changes would not set in; the effluent from the precipitation tanks could be oxidized on beds 6 feet deep, whereas the beds would have to be 9 feet deep if they were to treat a settled or septic effluent separately; no costly process would be needed for the removal of solids from the effluent or the filter bed; the filters would be of a permanent character, if properly constructed; during heavy rains five times the dry-weather flow could be successfully treated.

The new works provide for the sewage of 650,000 persons with a dry-weather flow of 48 U. S. gallons per capita per day, or a total of 31,200,000 gallons. During storms the works will care for a flow of 4.6 times this amount, or 144,000,000 gallons per day. Of this, the first 72,000,000 gallons receives full treatment and the remaining 72,000,000 gallons partial treatment in tanks as storm water.

The sewage first passes through coarse screens and grit chambers to remove the large solid particles. It is then pumped to the precipitation tanks and mixed with lime and, if necessary, other chemicals to eliminate the sludge. The effluent to the extent of 2.3 times the dry-weather flow is thence pumped to primary sprinkling filters through which it is passed by gravity to humus tanks or, if necessary, secondary sprinkling filters and so to the river. The second 2.3 times the dry-weather flow of effluent flows by gravity to the river after undergoing settlement in tanks in conjunction with treatment by chemical precipitation. The sludge resulting from the precipitation receives a dose of lime and is then pressed. The pressed cake is carried by railway to a site of 200 acres of low-lying land, where it is deposited and covered with a thin layer of surface soil. In 1913, 10,000 tons of sludge cake was consigned to farmers.

The sprinkling filters cover an area of 42 acres with a depth of 6 feet. In the year 1913 the quantity of sewage dealt with at the Knostrop works averaged 22,100,000 gallons or 50.7 gallons per capita per day.

London

Imperfect methods of drainage resulted from the introduction of house drainage into the sewers after the year 1847. A commission known as the Metropolitan Commission of Sewers was created to improve the conditions, and this board superseded eight distinct and independent bodies which had formerly exercised authority over the London sewers. Within 6 years 30,000 cesspools were abolished, the houses being connected directly with the sewers.

This improvement to the drainage of the city was accompanied by decided injury to the river Thames and the public press began to agitate for a remedy. After various commissions had been appointed between 1849 and 1854, the Metropolitan Board of Works was created in 1856. The main drainage works which now exist are due to the initiative of that body which was especially created to put a stop to the pollution of the Thames. In 1899, the London County Council took over the work of main drainage and has since had authority over it.

In 1856 Sir Joseph Bazalgette, Chief Engineer of the Metropolitan Board of Works, reported as to the plans necessary to completely intercept the sewage of London and discharge it into the river below the Metropolis instead of directly into the river at about the level of low tide. As the tide rose, the sewage was ponded back into the sewers. Heavier ingredients were deposited and the liquids remained stagnant for long periods. The sewage was carried back and forth by the rising tide, progress toward

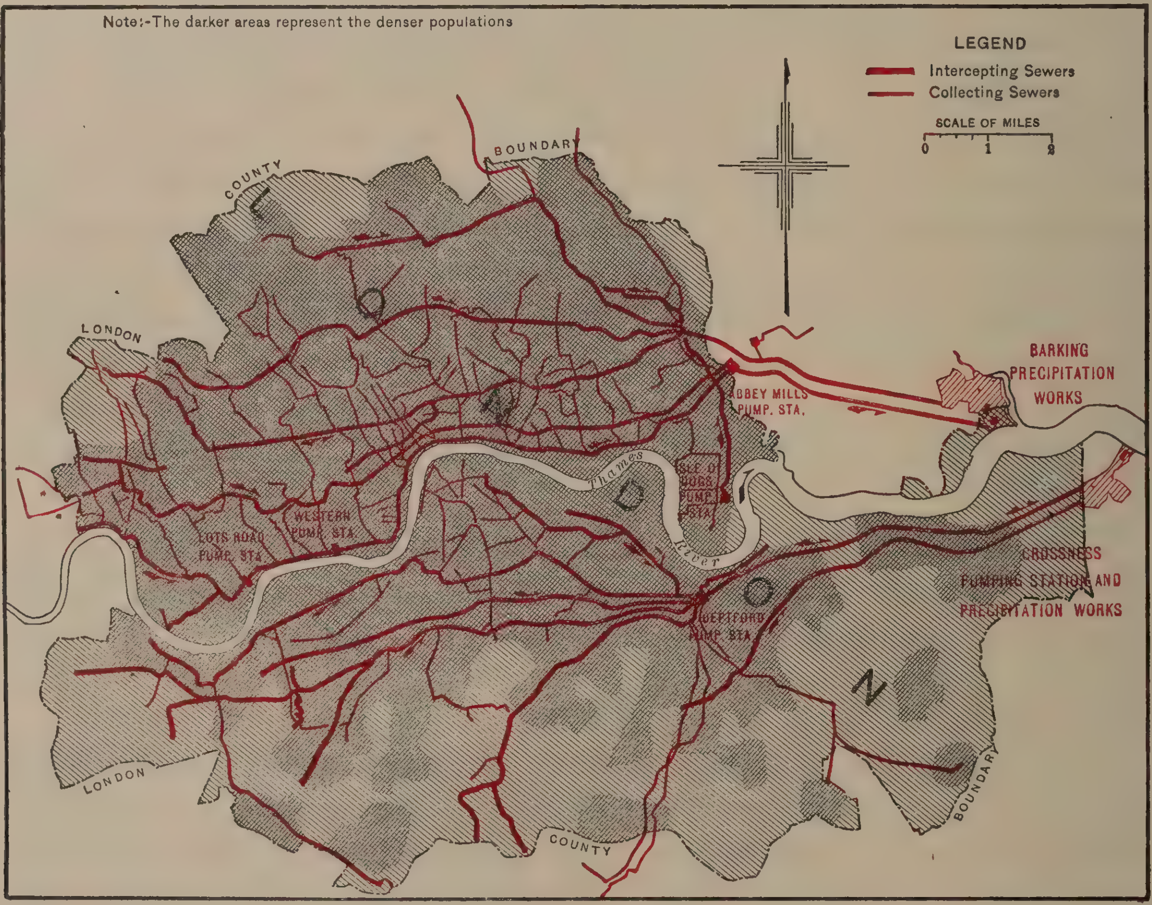


FIG. 19—LONDON

The sewage is carried to Barking and Crossness, beyond the city limits, where it is treated by chemical precipitation in covered tanks and the effluent discharged into the Thames. The sludge is taken to sea in tank steamers.

the sea being very slow. The condition of the Thames was exceedingly offensive, receiving, as it did, the sewage of nearly 3,000,000 people in the midst of the city.

According to Budd, a prominent physician of the time: "Stench so foul, we may well believe, had never before ascended to pollute this lower air. For many weeks the atmosphere of Parliamentary committee rooms was only rendered barely tolerable by the suspension before every window of blinds saturated with chloride of lime and by the lavish use of this and other disinfectants. More than once, in spite of similar precautions, the law courts were suddenly broken up by an insupportable invasion of the noxious vapor. The river steamers lost their accustomed traffic, and travelers, pressed for time, often made a circuit of many miles rather than cross one of the city bridges."

The main feature of the scheme devised by the Metropolitan Board of Works was carried out between 1856 and 1874. It consisted of the construction of intercepting sewers with which the main sewers, which previously delivered sewage into the river, were connected. The intercepting sewers were carried to Barking on the north side of the river, 11 miles below London Bridge and to Crossness on the south side of the river, 13 miles below London Bridge. The objects to be attained were to keep the sewage out of the river within the city limits, to substitute a constant instead of intermittent flow in the sewers, to abolish the tide-locked sewers with their constant accumulation of deposited matters and to substitute deeper and better sewers with improved gradients and outfalls.

Eventually three classes of sewers came under the control of the Metropolitan Board: Main sewers running at right angles to the river; intercepting sewers parallel to the river, and outfall sewers running parallel to the river and beyond the intercepting sewers. These main drainage works received their sewage from local sewerage systems under the control of the vestries and district boards and now under the municipal borough councils of the many cities of which London is composed.

The system was designed for a population of 3,450,000 persons and 129,600,000 U. S. gallons of dry-weather flow collected in combined sewer systems. The amount of rainfall admitted was rather more than 2½ times the dry-weather flow. The old sewers were used for storm overflows.

In course of time the population increased beyond the provisions already made and additional intercepting and storm relief sewers had to be constructed. The average daily flow of sewage discharged at both outfalls for 1911-12 was 386,500,000 gallons per day.

The total discharging capacity of the Barking and Crossness works is about 859,000,000 and 943,000,000 gallons per 24 hours, respectively. The population draining into the Council's sewers in 1911 was 5,336,100.

The net capital expenditure of the Metropolitan Board of Works and the London County Council up to March 31, 1912, was $60,971,770. The total length of main intercepting and storm sewers is about 370 miles.

The sewage which was carried to Barking and Crossness was at first discharged from reservoirs on the outgoing currents. A marked improvement was visible in the Thames after a time. Ten years after the opening of the works, it became apparent that the river was being overtaxed and the experience of years before in a crowded section of the city, when the sewage was carried back and forth and produced a nuisance, was, in a measure, repeated near the works.

In 1869, 1878 and 1882 inquiries were held and it was stated that sewage ought not to be discharged in a crude state in any part of the Thames. As a result of many experiments, it was decided to reconstruct the works at Barking and Crossness so as to treat the sewage on the principle of chemical precipitation. It was found that 56.96 parts per million of lime and 14.24 parts per million of protosulphate of iron were sufficient practically to remove the whole of the suspended matter and the grosser part of the offensive odors. It was expected that the liquid part of the sewage would be assimilated by the river water. This method of treatment was put into effect at Barking in 1889 and at Crossness in 1891.

The sewage receives the chemicals as it enters the works and then flows through underground settling basins, of which there are 13 at Barking, varying in length from 860 to 1,200 feet with a width of 30 feet and a holding capacity of 24,000,000 gallons. The effluent flows from the basins into the river. At intervals of about 60 hours, each basin is shut off, the sewage withdrawn and the heavier suspended matters, called sludge, are pushed by hand labor to a sump and then passed through screens to storage tanks.

The storage tanks discharge the sludge, containing about 92 per cent. of moisture, to vessels which carry it to sea. The sludge vessels have a capacity of 1,000 tons each. They carry their cargo 57 miles below Barking to the mouth of the Thames estuary, where discharge takes place over a length of about 8 or 10 miles. Approximately 8,200 pounds of sludge were sent to sea daily in 1911. The vessels are of modern construction with twin screws and discharge their cargoes by gravity.

At Barking and Crossness, where the liquid part of London's sewage is discharged, the Thames is over 2,000 feet wide and has a range of tide of 18 feet. There is a flow of tidal water of 2,000 million cubic feet a day and, in addition, a discharge of 100,000 cubic feet of upland water. The effluents do not produce unsightly conditions. The river water is somewhat turbid, often more so than the sewage which is discharged into it. The average percentage of saturation of dissolved oxygen in 1912 was 20.8

at high water and 35.5 at low water near the Crossness works. During warm weather some odor is produced for 10 or 12 miles above and below the outfalls, but this is not noticeable much beyond the river banks.

Anticipating that it may be necessary to produce an effluent of greater purity than is possible by chemical precipitation, the London County Council has recently obtained an area of about 750 acres in the vicinity of Barking and Crossness, where improved methods of sewage disposal can be employed.

SALFORD

The Salford works occupy about 20 acres of land adjoining the Manchester Ship Canal and otherwise surrounded by a built-up section of the city. The works consist of chemical precipitation tanks, roughing filters, sprinkling filters and sludge tanks. The sludge is carrier to sea by a vessel, the distance traveled being 128 miles in the round trip.

Most of the sewage reaches the works from the main intercepting sewer, which is laid near the river Irwell, crossing the river at three points. About one-third of the sewage which is brought in the main interceptor flows through the works by gravity. The dry-weather flow is about 13,200,000 U. S. gallons, of which about 9,000,000 flow between 9 A. M. and 9 P. M. The average flow is between 15,600,000 and 19,200,000 gallons, and the greatest flow provided for is 38,400,000 gallons. As in most English towns, the sewers take storm water as well as house sewage and industrial drainage. Of the 13,200,000 gallons of dry-weather flow, about 7,920,000 gallons is domestic sewage, as estimated from the drinking water supply; about 3,600,000 is liquid trade waste and the remaining 1,680,000 is ground water. The ultimate flow provided for is 161 gallons per capita per day, reckoned on the basis of a population of about 231,000 in 1911.

At the disposal works, the main intercepting sewer has a sump sunk 2 feet below its invert from which a chain bucket dredger daily transfers by steam power such deposits as occur into cars which convey them to sludge tanks and so to sea by steamer.

There are three screening chambers controlled by valves. The screens are 3 feet wide, 13 feet high and have bars ¾ of an inch apart. From these screens the sewage is pumped between 20 and 30 feet to a mixing chamber from which it flows by gravity throughout the rest of the works. The sewage flows through the mixing chamber to a weir below which dissolved salts of iron are added, and about 20 yards further milk of lime is applied.

Settling tanks, five in number, are situated on each side of a central channel 10 feet wide, 4 feet deep and 550 feet long through which the sewage flows after receiving the chemicals. It is possible to conduct the flow through all of the 10 tanks in

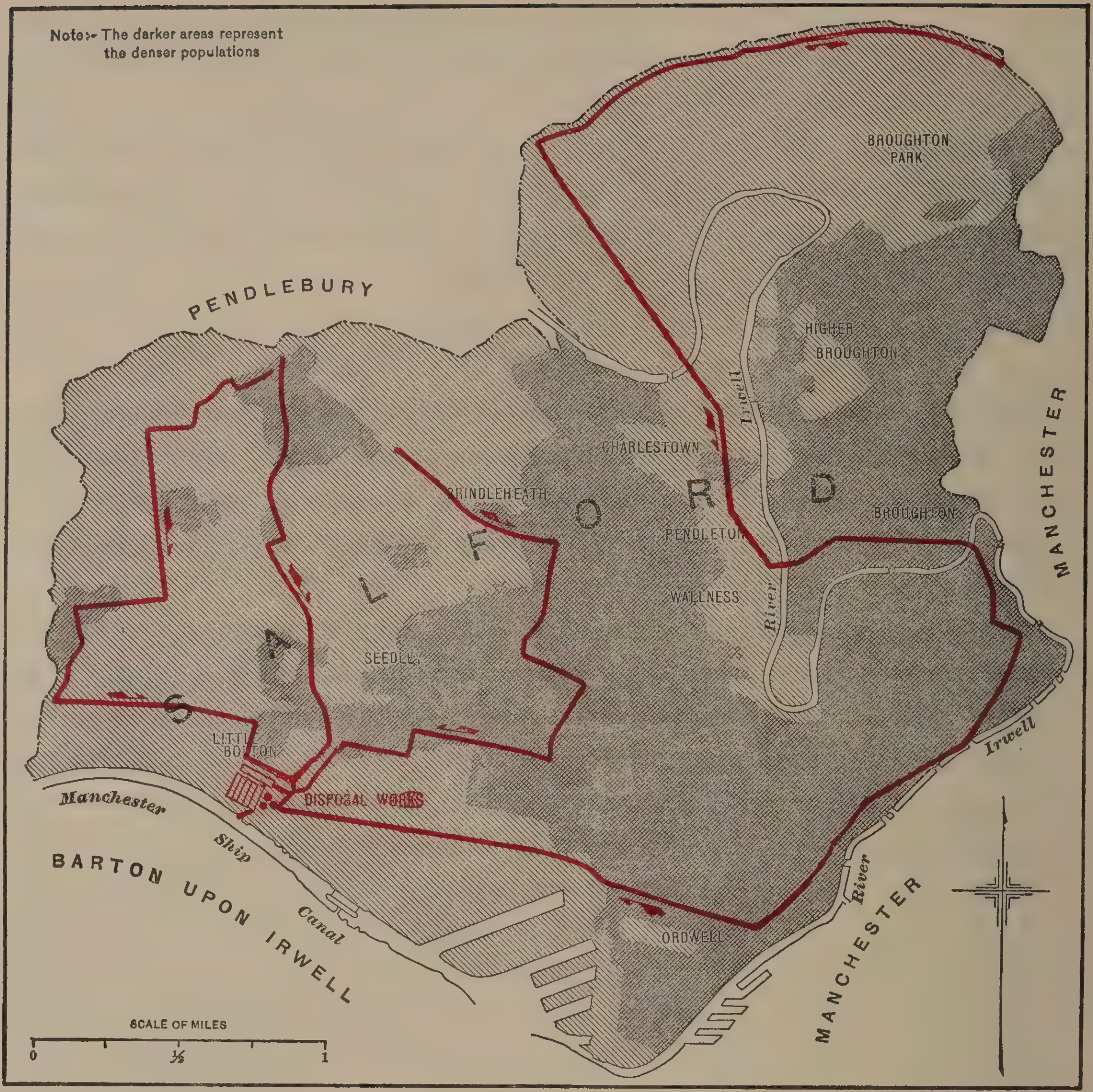


FIG. 20—SALFORD

The sewage is treated by chemical precipitation, roughing filters and sprinkling filters. The sludge is shipped to sea in tank steamers.

series or through groups of 5, 3 or 2 tanks. Sewage can also be carried through single tanks operated in parallel. Any tank can be shut off, emptied and cleaned when required. The capacity of the 10 tanks is 6,000,000 gallons. Each is about 150 feet long, 82 feet wide and from 7 to 10 feet deep. The sludge which is deposited here is carried away to sludge tanks which deliver it to the ship to be carried to sea.

The sewage is withdrawn from above the sludge and led to the roughing filters, of which there are six. Each roughing filter has a row of inlet holes supplied from a chamber in the outlet channel. The floor is of perforated tile set on short legs. The filtered material consists of 3 feet of gravel between one-sixteenth and five-sixteenths inch in diameter. Their object is to remove matter in suspension and especially colloidal matter which has escaped the precipitation tanks. About three tons, reckoned as dried material, are removed daily. The roughing filters are washed by an upward or reverse current, the washing process being facilitated by a system of air pipes fitted near the floor. The air is blown through these pipes at a pressure of 2 pounds per square inch, escaping by means of 4,800 holes of one-eighth inch diameter and 14 inches apart, thereby distributing the gravel and facilitating the upward flow of wash water.

The sewage passes to the sprinkling filters by means of 30-inch pipes with suitable branches and control valves and is distributed by means of spray jets, each serving an area 10 feet by 5 feet 2 inches.

The filter floors are concrete with culverts at 62-foot intervals for conveying the filtered sewage to the final outfall sewer, which is 4 feet in diameter. The earlier beds have ventilating manholes at each end and the beds recently constructed are provided with vent shafts and open sides to allow free airway.

The filtering material is crushed cinders and clinkers, the particles ranging in size from about three-sixteenths to three-quarters of an inch in diameter in the earlier beds and from one-quarter to one and one-quarter inches in diameter in the later beds, with some coarse material at the bottom. All the sprinkling filters have recently been emptied, the media washed and new media used as follows: 12 inches of material 3 to 5 inches in diameter, 7 feet of material from ¾ to 1½ inches, then another 12 inches of the existing washed material not less in size than half an inch, thus making the depth of the bed 9 feet.

The spray jets work under an available head of about 8 feet and these deliver at the rate of 62 gallons per square yard per hour, or 1,440 gallons per twenty-four hours, if running continually. There are 39,000 square yards of bed. It has been found desirable to run each bed for two hours and then rest it for 10 hours, according to the quantity of sewage to be dealt with. The effluent from the sprinkling filters discharges into the Manchester Ship Canal, formerly the river Irwell.

The sludge from the precipitation tanks flows to sludge tanks where men with push bars sweep it to an outlet leading to the sludge tanks, wading in the sludge with waterproof thigh boots. There are two sludge tanks, saucer shaped, 100 feet in diameter, 9 feet deep, holding about 3,000 tons of sludge. The sludge is pumped by double-acting piston pumps with a capacity of 200 tons per hour to a sludge steamer lying at a neighboring wharf. The steamer is 130 feet long, 13 feet beam, 11 feet draft loaded and carries 600 tons of sludge. The distance traveled to the dumping grounds, near the northwest lightship off Liverpool, is 64 miles. Four or five trips are made each week.

The management of the works has under consideration the questions of extending the two filter beds, the sprinkling filters and the provision of grit chambers and humus tanks.

SHEFFIELD

The sewage of Sheffield was discharged, untreated, into the rivers and water courses in the vicinity of the city until 1886, at which time main drainage works were completed and a sewage disposal plant was built to work on the principle of precipitation by means of lime and aeration over weirs, followed by continuous filtration through coke. A few years ago, it was decided to reconstruct the works so as to operate in accordance with the principles of sedimentation and subsequent oxidation in contact beds.

The city, which is one of the most important municipal centers in England has a population of about half a million. The natural elevations of the land are such as to make it unnecessary to pump the sewage at any point through the total length of 400 miles of sewers or to the outfall, which is about 8 miles from the farthest point at which any of the sewage enters the sewerage system.

At the time the reconstruction of the disposal works was begun, the plant covered about 23 acres. There were 30 precipitation tanks, each with a capacity of 60,000 U. S. gallons. The estimated average daily flow for which the works were designed was 12,000,000 gallons, but for some years a flow of approximately 20,400,000 gallons and a maximum of 26,400,000 gallons was treated.

The sludge produced amounted to between 800 and 1,000 tons a week, as measured in condition for removal. The sludge was carried away from the works by rail and pumped upon land, about 22 acres of country land being reserved for the purpose. In all about 1,000,000 tons of sludge have been dealt with in this manner.

The foregoing method of sewage disposal was not satisfactory to the Local Government Board and West Riding of Yorkshire Rivers Board and it was in consequence of this fact that Sheffield was compelled to adopt a more efficient process. Precipitation with lime came to be regarded as having no effect upon the dissolved impurities and was therefore incapable of preventing decomposition of the effluent when mingled with the river water.

Various ways of dealing with the sewage were considered, among them the construction of an outfall from Sheffield to the east coast of England by means of which the sewage could be discharged into the sea. Biological experiments were made of various methods of purifying the sewage, with the result that settlement, followed by treatment in contact beds, was eventually decided upon, after a full consideration of the results of the experiments, the difficulties of site, the trade wastes peculiar to the city and other local circumstances.

The settling tanks were to operate upon the contact principle with the understanding that if single contact did not accomplish the oxidizing effects wanted, second contact beds could be added. The reconstruction of the works represents an expenditure of about $2,000,000 and has had to be carried on without interference with the old works.

The new works are capable of dealing with a maximum flow of 77,400,000 gallons per 24 hours. This increase above the 12,000,000 gallons' capacity of the old works is due partly to the increase in population of Sheffield, but chiefly to the fact that the Local Government now requires six times the dry-weather flow to be treated during periods of storm. The average dry-weather flow is expected to be about 14,400,000 gallons per day.

The whole of the sewage will pass through catch-basins, grit chambers and settling tanks and the flow, up to 38,640,000 gallons, will be treated on contact beds.

The grit chambers are constructed in the form of double hoppers, between each of which a screening arrangement extends the whole length of the chamber. The screens are cleaned by hand rakes. This method of cleaning has worked so satisfactorily in the past that it has not been thought necessary to introduce mechanical appliances. The sand is removed from the grit chambers by two endless chain bucket elevators. Two other chambers have been added, fitted with a mechanical screening plant and with a traveling bucket dredger.

The sewage passes from the grit chambers to the settling tanks, which are 17 in number, and arranged on each side of a main feed conduit. The total capacity of the tanks is 18,000,000 gallons or 1¼ times the estimated dry-weather flow. Up to the present, the sludge has been discharged into lagoons on the ground for temporary storage. The lagoons now cover an area of about 5 acres and have a working depth of 12 to 18 inches. After being partly dried, the sludge is loaded into cars and taken to the country to be dumped.

Sixty new contact beds are provided for in the new scheme, each bed having an area of one-half acre. The beds are composed of screened clinker, graded from coarse to medium size, with the finest on top. The depth is 4 feet.

CHAPTER III

RAINFALL AND THE RELATIONS BETWEEN THE VOLUMES OF DOMESTIC SEWAGE, STORM WATER AND TIDAL WATER IN NEW YORK HARBOR

The sewerage systems of New York and other municipalities in the Metropolitan district are described and the principles of their design, as far as ascertainable, are given in the report of the Commission dated April 30, 1910, pages 217 to 361, inclusive. The quantities of domestic sewage are there stated for the Metropolitan district and, so far as they relate to New York City, have been given in revised form in the Commission's preliminary report No. VI, dated February, 1913.* In the two reports mentioned will be found data giving the volumes of tidal water. The rainfall data which have been compiled by the commission are stated for the first time in this place.

The volume, intensity and frequency of rain-storms have an important bearing on the question of sewage disposal, especially in those cases, as at New York, where the sewers are built upon the combined plan.

With respect to volume, the water which falls in the built-up parts of the city during the course of a year in the form of rain and snow and flows away to the sewers bears a very small proportion to the quantity of domestic sewage. The volume of storm water seems greater than it really is, probably because of its appearance in the streets and on account of the large size of the sewers which are built to carry it off, but it is to be remembered that there are many days when no storm water is produced, whereas the ordinary flow of domestic sewage is continuous. Excepting in rural districts, where little or no sewage is produced, the volume of storm water is small as compared with the dry-weather flow.

The frequency of rain-storms of sufficient intensity to wash the dirt of the streets into the sewers must be taken into consideration. The first flush of storm water from a city is often more foul than house sewage, and the more intense and less frequent the storms, the greater is the quantity of polluting matter which is likely to be carried with the initial rush. In addition to the washings of the streets, the deposits which exist in some parts of nearly all sewers are likely to be scoured away and these may add considerably to the solid matters discharged by the sewers.

The first effect of a storm is to increase both the volume and concentration of the sewage, and this effect is greater or less depending on the violence and duration of the storm. When rain-storms continue for long periods of time their effect is to dilute the sewage. The scouring and flushing actions which occur at first gradually cease for want of solid matter to dissolve or wash away and the water which enters the sewers from the streets and roofs becomes less polluted than the ordinary domestic sewage.

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*See Part II, Chapter II, page 46 of this report.

Allowance for Storm Water

It is customary in designing sewage disposal works which are to deal with the combined sewage of houses and streets to provide a plant sufficient to handle the dry-weather flow and some of the first flush of storm water. In the studies made by this commission for main drainage and disposal works for New York, allowance has been made for storm water by providing for twice the average dry-weather flow. This provision gives room for the maximum discharge of domestic sewage, which may be 50 per cent. above the average at certain hours of the day and makes it possible to deal with a considerable amount of storm water, provided it falls at a time when the ordinary domestic flow is not at a maximum.

The importance of giving careful consideration to the rainfall is greater in designing collecting systems of sewers than in providing for final disposition. The function of such sewers is not only to carry off the drainage of the houses, but to prevent accumulations of water in the streets. It sometimes happens, when excessive falls of rain occur, that sewers are surcharged. At such times the drainage of houses is interfered with and often stopped, in which case cellars may be flooded and other serious inconvenience produced.

It is usually impracticable to provide combined sewers of a size and grade sufficient to carry away the water which falls in storms with sufficient promptness to insure that inconvenience from flooding shall never occur. At long intervals rainfalls of exceptional severity take place, and to provide for these, sewers would have to be built so very large that they would represent a considerable investment over the sum required to give them sufficient capacity for all the ordinary and most of the heavy rains which are likely to fall.

Fig. 21 shows the comparative size of sewers intended to accommodate domestic sewage, ordinary storm and house sewage and the greatest probable amount of storm water with the same amount of house sewage as is provided in other instances.

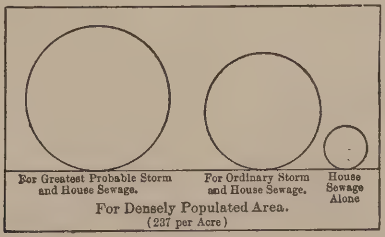

For Greatest Probable Storm and House Sewage.
For Ordinary Storm and House Sewage.
House Sewage Alone
For Densely Populated Area.
(237 per Acre)

FIG. 21

Relative Sizes of Sewers for Combined Storm Sewage and House Sewage

The assumption upon which this figure has been drawn is that the area is populated to the extent of about 237 persons per acre. Under some circumstances the volume of storm water may be nearly 80 times the volume of domestic flow; about 2 per cent. of the annual rainfall may reach a combined sewer in 15 minutes.

Studies have been made by the commission to show the amount of storm water entering New York harbor from various parts of New York City. The divisions, areas and volumes of domestic sewage correspond with Figures 1 and 2, page 18, and Fig. 9, page 30, of the report of this commission dated August 1, 1912, as near as practicable, where the areas were tributary to the various parts of the harbor waters.

The rainfall was taken from the United States Weather Bureau records from 1875 to 1912, inclusive. The yearly average was 43.97, the minimum 35.73 and the maximum 58.68 inches. The runoff was assumed to be from 40 to 80 per cent., according to the density of population of the various parts of the drainage areas.

Table XCII has been prepared to show the estimated relative volumes of storm water and domestic sewage entering various parts of the Harbor from New York City.

TABLE XCII

Estimated Relative Volumes of Storm Water and Domestic Sewage Entering Various Parts of the Harbor from New York City.

Drainage to	Acres			Millions of cubic feet Daily				Per cent. of Volume of Sewage		Population Thousands	Density Persons per Acre
	Net	Parks	Total	Rain	C	Run-off	Sewage	Rain	Run-off		
Hudson............[1]	5,122	349	5,471	2.39	85	2.03	33.50	7.1	6.1	1,562.6	306
Harlem............[2]	8,783	1,759	10,542	4.61	60	2.77	40.29	10.7	6.9	2,105.8	239
Upper East river...[3]	39,717	2,431	42,148	18.43	40	7.37	6.64	277.6	111.0	304.8	8
Lower East river...	16,852	2,229	19,081	8.33	80	6.66	64.6	12.9	10.3	3,785.9	198
Jamaica bay.......[4]	53,659	——	——	23.47	50	11.74	27.20	86.3	43.2	1,415.7	26
Kill van Kull......[5]	6,647	——	——	2.91	60	1.75	7.91	36.8	22.1	432.9	65
Upper bay.........[5]	12,519	458	12,977	5.69	70	3.98	25.80	22.1	15.4	1,617.9	129

[1] From Harlem river to the Battery.

[2] Includes sewage from Hudson area, 573 acres, Harlem river to N. Line of City.

[3] Agrees with Preliminary Report IV.

[4] Agrees with Preliminary Report III.

[5] Agrees with Preliminary Report V.

Population and Sewage {
Manhattan and Brooklyn....................1960
Queens...1950
Bronx...1940

C Assumed percentage of rain flowing to streams.

Table XCII shows that the percentage of daily rainfall to daily sewage is about 7 per cent. in the most densely populated parts of the city. In the course of a day or month or year there is about ten times as much domestic sewage as storm water entering directly to the Lower East River. It will be observed that the annual rainfall has had a wide range in the 37 years for which records are available. The minimum of 35.73 inches, which is about 81 per cent. of the average, occurred in 1895 and the maximum of 58.68, or about 133 per cent. of the average, occurred in 1889.

INTENSITY OF RAINFALL

In regard to intensity of rainfall, marked variations have been observed. In the month of September, 1882, 14.51 inches fell, or about one-third of the total annual average. On the twenty-third day of the same month 6.17 inches fell in 24 hours, or 42½ per cent. of the monthly rainfall in one-thirtieth of the month.

The records of the United States Weather Bureau have been examined since observations were begun for the heaviest rainfalls which have occurred in brief intervals of time. The intensities lasting 5, 10, 15 and 30 minutes and 1 and 2 hours have been taken from the records and are here presented. The earliest records were made in 1896. The rainfall in 5, 10 and 60 minutes was observed from this time forward with the exception of December, 1896, June, 1897, and February, 1898. The records for periods of 15, 30 and 120 minutes were begun in January, 1903, and continued to the present time.

These records are all contained in Table XCIII, which, for convenience, has been arranged to show the intensity of precipitation according to years, months and the brief periods of time here stated.

TABLE XCIII

NEW YORK CITY—GREATEST MONTHLY PRECIPITATION IN INCHES IN 5-MINUTE, 10-MINUTE, 15-MINUTE, 30-MINUTE, 1-HOUR AND 2-HOUR PERIODS, 1896 TO 1911, INCLUSIVE.

Year	January						February						March					
	5m.	10m.	15m.	30m.	1h.	2h.	5m.	10m.	15m.	30m.	1h.	2h.	5m.	10m.	15m.	30m.	1h.	2h.
1896	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1897	—	—	—	—	—	—	.04	.06	—	—	.25	—	.03	.05	—	—	.19	—
1898	.06	.08	—	—	.30	—	—	—	—	—	—	—	.04	.06	—	—	.16	—
1899	.07	.11	—	—	.39	—	.03	.05	—	—	.24	—	.08	.12	—	—	.40	—
1900	.06	.10	—	—	.42	—	.08	.17	—	—	.55	—	.04	.07	—	—	.24	—
1901	.03	.05	—	—	.12	—	.02	.03	—	—	.08	—	.12	.22	—	—	.64	—
1902	.04	.07	—	—	.14	—	.05	.09	—	—	.35	—	.05	.07	—	—	.21	—
1903	.06	.10	.13	.20	.36	.54	.10	.12	.13	.14	.20	.35	.10	.15	.16	.19	.27	.29
1904	.04	.06	.08	.17	.29	.47	.03	.04	.06	.11	.18	.29	.07	.10	.11	.15	.23	.33
1905	.05	.09	.11	.19	.30	.53	.04	.06	.08	.15	.26	.47	.04	.06	.07	.11	.17	.30
1906	.06	.10	.14	.24	.43	.65	.06	.10	.14	.18	.30	.41	.04	.06	.09	.15	.28	.52
1907	.05	.06	.08	.13	.25	.47	.02	.04	.05	.10	.12	.22	.11	.13	.14	.19	.29	.45
1908	.06	.11	.15	.25	.37	.69	.06	.10	.13	.23	.43	.77	.04	.06	.06	.10	.16	.24
1909	.07	.10	.12	.19	.38	.47	.05	.10	.13	.18	.25	.36	.06	.10	.12	.23	.40	.74
1910	.06	.10	.13	.19	.24	.31	.07	.11	.15	.21	.36	.71	.06	.08	.09	.14	.20	.23
1911	.07	.10	.11	.11	.19	.28	.13	.17	.21	.31	.53	.80	.13	.19	.22	.25	.27	.43

NOTE.—Record has only been made of the greatest intensity for each period during the month. Other storms of high and equal, or less, intensity may have occurred during the same month.

TABLE XCIII—Continued

Year	April						May						June					
	5m.	10m.	15m.	30m.	1h.	2h.	5m.	10m.	15m.	30m.	1h.	2h.	5m.	10m.	15m.	30m.	1h.	2h.
1896	.03	.06	—	—	.22	—	.15	.25	—	—	.46	—	.19	.31	—	—	.56	—
1897	.05	.10	—	—	.20	—	.20	.36	—	—	.68	—	.42	.57	—	—	.69	—
1898	.26	.30	—	—	.36	—	.09	.16	—	—	.28	—	.12	.15	—	—	.24	—
1899	.02	.04	—	—	.16	—	.05	.09	—	—	.24	—	.16	.25	—	—	.46	—
1900	.05	.07	—	—	.25	—	.18	.28	—	—	.98	—	.26	.50	—	—	1.55	—
1901	.09	.15	—	—	.43	—	.16	.19	—	—	.40	—	.10	.12	—	—	.32	—
1902	.06	.10	—	—	.44	—	.10	.20	—	—	.27	—	.22	.36	—	—	.67	—
1903	.04	.06	.08	.12	.20	.36	.07	.07	.07	.08	.08	.09	.30	.41	.48	.74	1.30	1.94
1904	.09	.13	.15	.23	.34	.45	.22	.25	.28	.37	.42	.43	.17	.23	.29	.35	.35	.38
1905	.07	.09	.11	.17	.23	.28	.09	.13	.15	.17	.19	.19	.38	.61	.66	.66	.66	.87
1906	.10	.18	.24	.36	.64	.91	.35	.59	.68	.77	.94	1.06	.15	.23	.26	.32	.42	.48
1907	.10	.15	.20	.25	.28	.37	.15	.20	.23	.31	.47	.62	.09	.11	.13	.19	.26	.37
1908	.08	.11	.13	.26	.42	.62	.24	.34	.39	.45	.81	1.15	.09	.14	.19	.32	.45	.60
1909	.06	.11	.16	.22	.43	.71	.06	.06	.07	.09	.17	.28	.15	.18	.22	.34	.42	.42
1910	.14	.24	.27	.41	.53	.74	.09	.14	.15	.19	.22	.29	.25	.41	.48	.58	.63	.93
1911	.05	.06	.07	.14	.26	.37	.07	.12	.13	.13	.15	.21	.20	.32	.40	.53	.95	1.04

Year	July						August						September					
	5m.	10m.	15m.	30m.	1h.	2h.	5m.	10m.	15m.	30m.	1h.	2h.	5m.	10m.	15m.	30m.	1h.	2h.
1896	.40	.58	—	—	1.04	—	.19	.32	—	—	.39	—	.23	.27	—	—	.47	—
1897	.28	.40	—	—	.85	—	.32	.46	—	—	.75	—	.18	.26	—	—	.53	—
1898	.34	.44	—	—	1.27	—	.24	.26	—	—	.41	—	.12	.16	—	—	.39	—
1899	.27	.49	—	—	1.42	—	.31	.43	—	—	1.20	—	.22	.37	—	—	.95	—
1900	.34	.41	—	—	.65	—	.16	.27	—	—	.47	—	.12	.12	—	—	.31	—
1901	.38	.63	—	—	1.29	—	.48	.82	—	—	1.36	—	.25	.29	—	—	.34	—
1902	.47	.73	—	—	.88	—	.37	.65	—	—	.101	—	.07	.12	—	—	.26	—
1903	.23	.39	.42	.50	.50	.55	.10	.11	.15	.25	.46	.83	.14	.25	.29	.41	.84	1.10
1904	.19	.27	.27	.48	.59	.63	.40	.64	.78	1.18	1.66	1.80	.25	.38	.40	.61	.80	1.10
1905	.74	1.26	1.63	2.09	2.30	2.58	.20	.36	.48	.80	.98	.98	.20	.27	.33	.60	1.00	1.38
1906	.19	.28	.33	.44	.64	.69	.52	.97	1.22	1.35	1.36	1.36	.16	.31	.47	.63	.89	.96
1907	.11	.15	.20	.20	.24	.37	.17	.30	.45	.66	.84	.97	.22	.33	.40	.59	.63	.83
1908	.39	.49	.75	1.14	1.22	1.52	.15	.29	.30	.47	.74	1.23	.10	.13	.16	.27	.42	.56
1909	.18	.26	.31	.33	.33	.45	.12	.16	.24	.39	.60	.87	.09	.13	.14	.15	.20	.36
1910	.06	.07	.08	.11	.11	.11	.22	.43	.55	.70	.73	.73	.05	.08	.12	.19	.28	.48
1911	.10	.17	.81	.20	.22	.30	.16	.28	.34	.44	.53	.72	.07	.12	.15	.16	.21	.38

Year	October						November						December					
	5m.	10m.	15m.	30m.	1h.	2h.	5m.	10m.	15m.	30m.	1h.	2h.	5m.	10m.	15m.	30m.	1h.	2h.
1896	.03	.05	—	—	.19	—	.05	.08	—	—	.18	—	—	—	—	—	—	—
1897	.08	.12	—	—	.18	—	.09	.18	—	—	.47	—	.07	.11	—	—	.45	—
1898	.36	.53	—	—	.57	—	.06	.10	—	—	.31	—	.10	.14	—	—	.24	—
1899	.07	.09	—	—	.27	—	.06	.08	—	—	.17	—	.06	.08	—	—	.20	—
1900	.17	.27	—	—	.88	—	.14	.21	—	—	.53	—	.05	.08	—	—	.32	—
1901	.09	.11	—	—	.23	—	.02	.03	—	—	.14	—	.04	.07	—	—	.26	—
1902	.19	.32	—	—	.57	—	.03	.04	—	—	.11	—	.09	.15	—	—	.32	—
1903	.28	.41	.65	.99	1.49	2.42	.08	.12	.12	.15	.26	.31	.02	.04	.06	.11	.20	.39
1904	.12	.19	.26	.38	.66	1.13	.07	.11	.14	.14	.38	.47	.02	.03	.04	.07	.14	.25
1905	.12	.19	.25	.30	.36	.56	.03	.05	.07	.10	.18	.31	.08	.16	.22	.30	.56	.68
1906	.19	.25	.31	.33	.43	.60	.02	.04	.04	.07	.13	.24	.05	.10	.15	.21	.30	.45
1907	.13	.20	.23	.32	.48	.63	.06	.11	.11	.21	.34	.48	.11	.12	.14	.25	.42	.77
1908	.21	.31	.40	.58	.64	.65	.02	.03	.04	.07	.14	.20	.08	.13	.18	.23	.36	.57
1909	.07	.08	.08	.08	.14	.21	.03	.05	.06	.10	.16	.20	.12	.20	.24	.47	.66	.97
1910	.18	.30	.42	.70	.91	1.31	.04	.08	.11	.20	.37	.63	.02	.03	.05	.09	.18	.35
1911	.09	.10	.13	.19	.31	.42	.04	.08	.12	.21	.34	.65	.03	.06	.07	.10	.15	.24

From Table XCIII, Table XCIV has been prepared to show the variations which have occurred in the rates of precipitation. These rates have varied from 1 to 9 inches per hour. The data are arranged according to the rate of precipitation and the periods of time during which these rates were continued. The greatest rate was 8 inches per hour and this was continued for 5 minutes.

TABLE XCIV

Number and Percentage of Months in Which the Rate of Precipitation Exceeded 1 Inch per Hour.

(See Note on Page 6.)

	Period	5 Min.	10 Min.	15 Min.	30 Min.	60 Min.	120 Min.
	Total Months Observed	186	186	108	108	186	108
Rate of Precipitation in Inches per Hour	1.00	101 =54.3%	78 =41.9%	34 =31.4%	20 =18.5%	15 =8.1%	2 =1.1%
	1.25	80 =43.0%	64 =34.3%	23 =21.3%	13 =12.0%	10 =5.4%	1 =0.5%
	1.50	69 =37.1%	59 =31.7%	19 =17.6%	7 = 6.5%	3 =1.6%	0 =0.0%
	1.75	63 =33.9%	42 =22.6%	13 =12.0%	5 = 4.6%	1 =0.5%	—
	2.00	53 =28.5%	27 =14.5%	8 = 7.4%	4 = 2.15%	1 =0.5%	—
	2.50	36 =19.4%	19 =10.2%	7 = 6.5%	2 = 1.1%	0 =0.0%	—
	3.00	26 =14.0%	13 = 7.0%	4 = 3.7%	1 = 0.9%	—	—
	3.50	18 = 9.7%	8 = 4.3%	2 = 1.9%	1 = 0.9%	—	—
	4.00	15 = 8.1%	4 = 2.15%	2 =1.85%	1 = 0.9%	—	—
	4.50	10 = 5.4%	3 = 1.6%	2 = 1.8%	0 = 0.0%	—	—
	5.00	5 = 2.7%	2 = 1.1%	1 = 0.9%	—	—	—
	6.00	3 = 1.6%	1 = 0.5%	1 = 0.9%	—	—	—
	7.00	1 = 0.5%	0 = 0.0%	0 =0.0%	—	—	—
	8.00	1 = 0.5%	—	—	—	—	—
	9.00	0 = 0.0%	—	—	—	—	—

To facilitate the use of the data contained in Tables XCIII and XCIV curves have been prepared to show the most important facts with regard to the intensity of rainfall. Fig. 22 gives the frequency of rates of different intensities for various periods of time, arranged according to the percentage of months in which they have occurred.

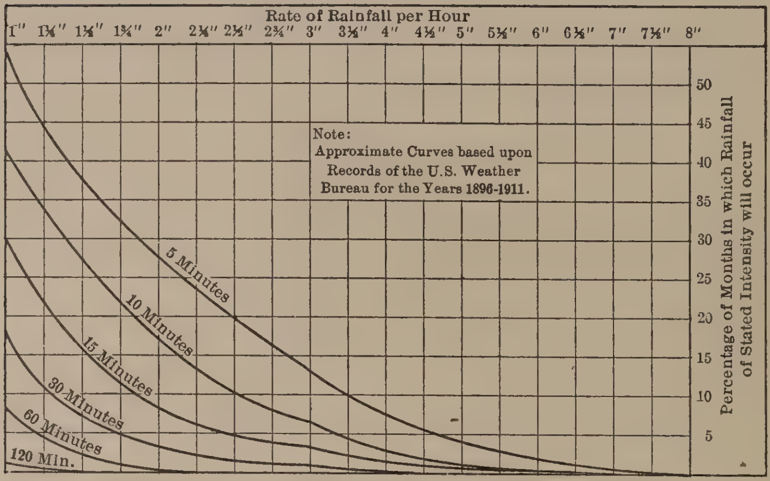


FIG. 22

Frequency of Rainfalls of Different Intensities
Manhattan

Fig. 23 shows the frequency of various intensities which have lasted for 5 minutes, arranged so as to indicate the number of times which they have occurred per year and the mean interval in months which has occurred between storms.

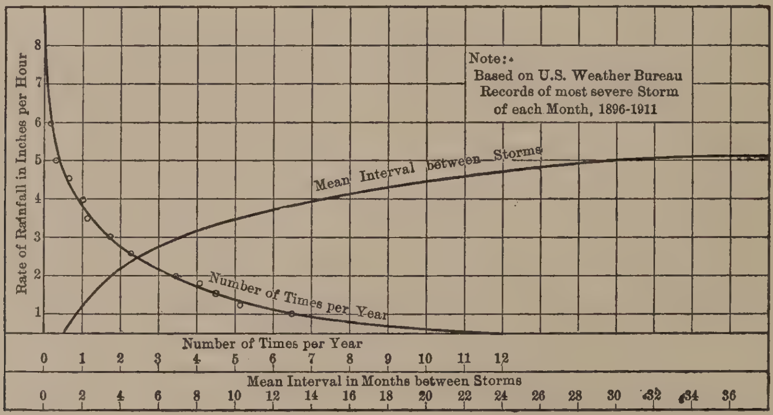
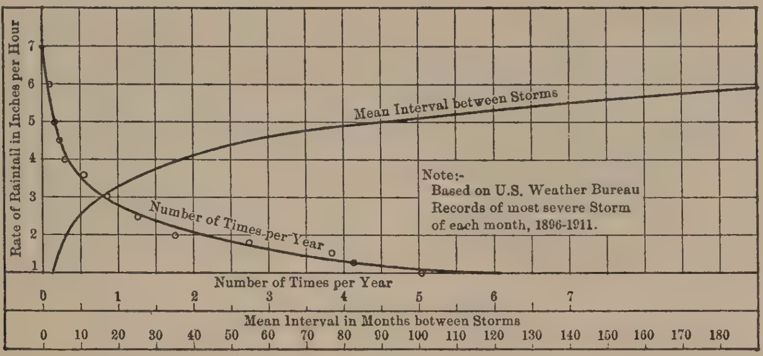


FIG. 23

Frequency of Rainfalls of Different Intensities for 5 Minute Periods
Manhattan

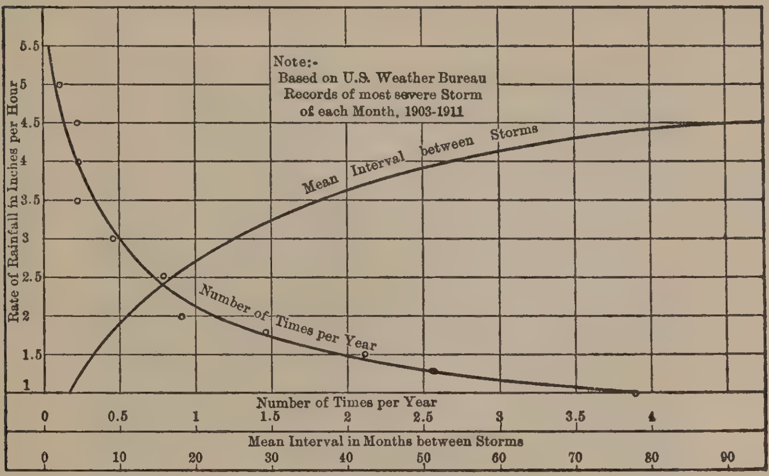
Figs. 24, 25 and 26 are uniform with Fig. 23 except that they cover rates which were maintained for longer periods.



Note:-
Based on U.S. Weather Bureau
Records of most severe Storm
of each month, 1896-1911.

FIG. 24

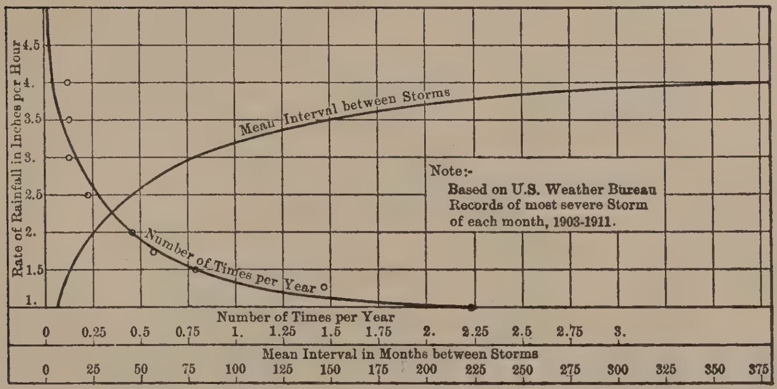
Frequency of Rainfalls of Different Intensities for 10 Minute Periods
Manhattan



Note:-
Based on U.S. Weather Bureau
Records of most severe Storm
of each Month, 1903-1911

FIG. 25

Frequency of Rainfalls of Different Intensities for 15 Minute Periods
Manhattan



Note:-
Based on U.S. Weather Bureau
Records of most severe Storm
of each month, 1903-1911.

FIG. 26

Frequency of Rainfalls of Different Intensities for 30 Minute Intervals
Manhattan

EXAMPLE OF A SEVERE RAINFALL

A rain-storm of unusual severity occurred in New York on October 1, 1913. The study which the commission made of it will serve to show how beneficial a rainfall may be in diluting the polluted water of the harbor. In this study the harbor has been considered to consist of ten divisions defined by the commission in its previous reports. The rainfall, as observed at a number of stations maintained chiefly by the Weather Bureau, has been computed for the drainage areas tributary. The runoff data for the land surfaces within the Metropolitan district are based upon the figures stated in Table XCII, increased somewhat because of the unusual length and character of the rainfall.

The rain gauge records used were those of the Weather Bureau stations at the Whitehall Building and Central Park in Manhattan, the Brooklyn Eagle Building in Brooklyn, of the Sewer Bureau at the Bronx Borough Hall, Westchester and Richmond Borough Hall and of the City Engineer at the Newark City Hall. The location of the rain gauges from which the rainfall records were taken is indicated in Fig. 27.

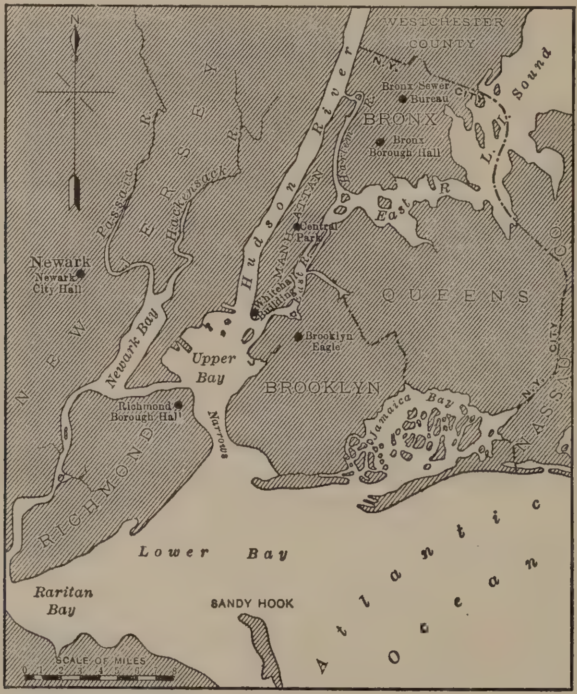


FIG. 27
Rain Gauge Stations

The records from the foregoing gauges varied somewhat so that it seemed desirable to take an average of two or more to show the amount of rain which fell in the different areas. Some idea of the character of the storm, particularly the varying rates of precipitation can be obtained from Fig. 28, which has been prepared from data collected at the Weather Bureau Office in the Whitehall Building near the center of the Metropolitan district.

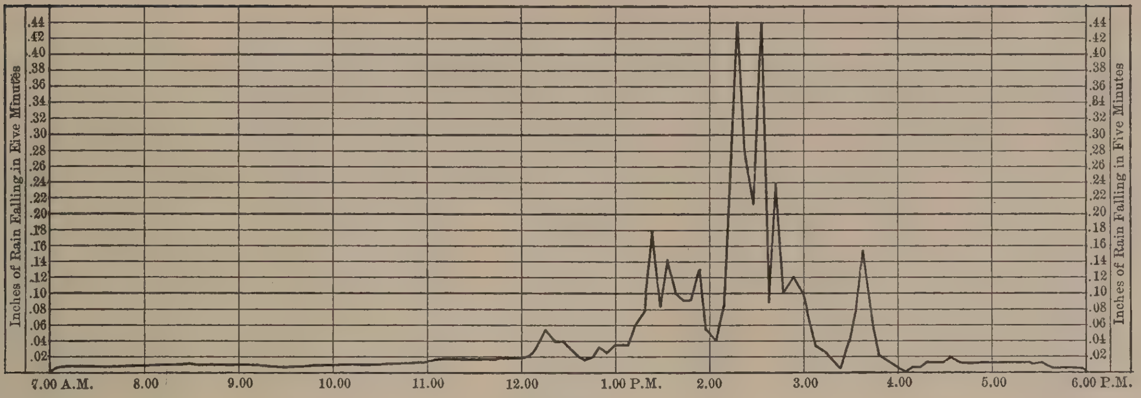


FIG. 28

Intensities of Rainfall, Storm of October 1, 1913, as Observed by the U. S. Weather Bureau, at Whitehall Building, New York City

Fig. 28 shows that the storm was characterized by low rates of precipitation from 7 A. M. until about noon, when the severity increased until between 2 and 3 in the afternoon, when it reached a maximum. After 4 o'clock the rate of rainfall was comparatively insignificant. During the preceding day the weather had been cloudy with slight precipitation. At its height there was a period of 5 minutes, during which 0.44 inch of rain fell, this being 8.5 per cent. of the total of the storm. During 10 minutes 0.77 inch fell, or 15 per cent. of the total. In 30 minutes a fall of 1.64 was recorded, or 32 per cent. of the total.

Table XCV shows the volume of water which was discharged on land and the volume of rain which fell upon water surfaces in the Metropolitan district as a result of the storm of October 1.

TABLE XCV

VOLUME OF WATER WHICH WAS DISCHARGED ON LAND AND THE VOLUME OF RAIN WHICH FELL UPON WATER SURFACES IN THE METROPOLITAN DISTRICT AS THE RESULT OF THE STORM OF OCTOBER 1, 1913.

FROM LAND

Division	Trib. Area Acres	Rainfall Inches	Rainfall Feet	Per cent. Run-off	Total Acre-Feet	Amount Mil. Gal.
Harlem river	12,100	4.39	.366	70	3,099	1,012
Hudson river	11,200	5.40	.450	90	4,541	1,485
Upper East river	36,400	3.61	.301	55	6,020	1,968
Lower East river	19,100	4.96	.413	85	6,710	2,192
Upper bay	15,100	5.82	.485	75	5,450	1,781
Kill van Kull	12,600	7.69	.641	70	5,654	1,849
Jamaica bay	53,700	4.59	.383	65	13,350	4,362
Newark bay	114,400	6.80	.567	55	45,050	14,730
Arthur Kill	80,700	7.69	.641	65	33,600	10,985
Lower bay	24,700	6.14	.512	65	8,220	2,688
Total from land						43,052

TABLE XCV—Continued

RAINFALL ON WATER

Division	Area Acres	Rainfall Feet	Volume Mil. Gal.	Volume from Land Mil. Gal.	Total Volume Entering Harbor Mil. Gal.	Total Volume Entering Harbor Mil. cu. ft.
Harlem river	639	.366	76	1,012	1,088	145.5
Hudson river	9,670	.450	1,422	1,485	2,907	388.6
Upper East river	6,409	.301	631	1,968	2,599	347.4
Lower East river	2,738	.413	370	2,192	2,562	342.6
Upper bay	12,485	.485	1,981	1,781	3,762	503.3
Kill van Kull	659	.641	138	1,849	1,987	265.6
Jamaica bay	13,760	.383	1,724	4,362	6,086	814.0
Newark bay	5,158	.567	955	14,730	15,685	2097.0
Arthur Kill	2,662	.641	558	10,985	11,543	1543.0
Lower bay	78,950	.512	13,155	2,668	15,843	2118.0
Total storm water entering harbor					64,062	8565.0

From Table XCV it appears that the fall of rain approximately in 11 hours from 7 A. M. to 6 P. M. varied between 3.61 in the Upper East river section to 7.67 in the neighborhood of Staten Island. The total amount of water which ran off to the harbor according to these calculations amounted to 43,052 million gallons. A large amount of rain fell directly upon the water surfaces and this increased the total precipitation which reached the harbor to 64,062 million gallons, or 8,565 million cubic feet. This is equivalent to 216,200 cubic feet per second for 11 hours.

Table XCVI has been prepared with the object of comparing the volume of storm water discharged on October 1 with the volumes of water already in the harbor and passing through the harbor under ordinary weather and tidal conditions.

TABLE XCVI

COMPARISON OF THE VOLUME OF STORM WATER DISCHARGING ON OCTOBER 1 WITH THE VOLUME OF WATER ALREADY IN THE HARBOR AND PASSING THROUGH THE HARBOR UNDER ORDINARY WEATHER AND TIDAL CONDITIONS.

1 Division	2 Total storm water entering Mil. cu. ft.	3 Volume below M. L. W. Mil. cu. ft.	4 Ratio 2:3	5 Tidal Prism. Mil. cu. ft.	6 Ratio 2:5	7 Resultant flow towards Sandy Hook Mil. cu. ft.	8 Ratio 2:7
Harlem river	145.5	285	1:2	148	1:1	15	9.7:1
Hudson river	388.6	12,330	1:32	1,697	1:4.4	1,087	1:2.8
Upper East river	347.4	5,512	1:16	1,869	1:5.4	*115	3:1
Lower East river	342.6	4,174	1:12.2	552	1:1.6	100	3.4:1
Upper bay	503.3	12,970	1:26	2,541	1:5.1	1,283	1:2.5
Kill van Kull	265.6	728	1:2.7	150	1.8:1	88	3:1
Jamaica bay	814.0	2,258	1:2.8	2,309	1:2.8	24	34:1
Newark bay	2097.0	1,542	1.4:1	1,071	1.9:1	105	20:1
Arthur Kill	1543.0	1,735	1:1.1	743	2.1:1	33	47:1
Lower bay	2118.0	—	—	—	—	—	—
	8565.0						
Entire harbor, except Lower bay	6447	41,534	1:6.4	11,080	1:1.7	†1,315	4.9:1

---

* Differs from Lower East river by amount of resultant flow of Harlem river.

† Resultant flow through Narrows increased by that of Arthur Kill.

Table XCVI shows that the amount of rain which fell directly upon the water surfaces of the harbor above the Narrows and ran off from the land immediately tributary to the harbor was equivalent to 216,200 cubic feet per second. This is 9 times the average land water discharge rate of the entire Hudson river; 17 times the dry-weather land water discharge rate of that stream and 7½ times the resultant rate of ebb flow of harbor water through the Narrows.

The total volume of 8,565 million cubic feet is equal to 4 times the total mean daily land water discharge volume of the Hudson river, 7½ times the mean daily land water discharge of that stream and 6½ times the total resultant ebb flow of harbor water through the Narrows in one tidal cycle of 12 lunar hours.

Comparing the volumes of storm water entering the various divisions of the harbor contained in those divisions at mean low tide, in the tidal prism and in the resultant flow toward Sandy Hook, a number of facts become apparent. The quantity of rain water which entered the Harlem river was equal to the tidal prism of that strait or the volume of water between the levels of high and low tide. Approximately the same is true for the Lower East river. The rain water which entered Newark bay was about twice the tidal prism.

With respect to the proportion between the rain water and the normal net ebb flow through the various sections, the following facts were established: About 3½ times as much rain water entered the Lower East river as there is net ebb flow through that section. Nearly ten times as much rain water entered the Harlem river as there is resultant flow through that strait. In Newark bay and Jamaica bay the proportion was very much greater. The rain water which entered Upper New York bay was almost one-half of the volume of the net ebb flow through that part of the harbor.

In all cases these ratios are based upon the rainfall which fell upon the water surfaces and that which ran off from the areas of sections of the harbor mentioned. In no case is the rainfall upon neighboring territories or water surfaces included.

Considering the entire harbor, except Lower New York bay, it appears that nearly 5 times as much rain water entered the harbor as the net seaward discharge under ordinary circumstances. Speaking generally, the rain water was almost equal to the tidal prism and was equivalent to about one-sixth of the total water present beneath the level of mean low water.

Ratios of Sewage to Water in the Harbor

Some calculations of the ratios of sewage to water in New York harbor have been made by the Metropolitan Sewerage Commission which deal with comparatively small parts of the harbor and are consequently not greatly affected by the errors which are generally inseparable from such computations. But all calculations of this kind should be regarded as crude approximations of the truth.

There are three divisions of the water with which it is of interest to compare the sewage. First, the volume of water which is contained in the vicinity of an outlet at mean low tide; second, the volume of the tidal prism or quantity of water in the vicinity between the levels of low and high tide; third, the net ebb flow past the point where the sewage is emptied.

The Metropolitan Sewerage Commission has divided New York harbor into ten sections and the quantities of sewage which were discharged directly into these sections in 1910 have been estimated; the quantities of water in each section below mean low tide, in the tidal prism, and the net ebb flow through the section have been computed and the ratio between the sewage and the water has been calculated. Calculations based on estimates of future quantities of sewage have also been made.

In addition to these computations, estimates have been made of the aggregate weight of sewage impurities which are tributary to each section. These calculations are based on a definite composition of the sewage which is assumed and taken to be uniform for the whole territory. The composition assumed is that of the standard sewage as shown in Table III, Part II, Chap. II, page 47 of this report. The volume of the sewage for the year 1910 is based upon the public water supply. The volume expected in future is also founded upon anticipations of the drinking water requirements. The per capita volume of sewage being stated, it will be possible at any time to correct the estimates of weight of impurities discharged into the harbor in case either the composition or volume of the sewage becomes known. It is improbable that such knowledge can be obtained until main drainage works are built.

It has seemed desirable to calculate the quantities of sewage materials which would be discharged into the various sections of the harbor in case the sewage was first passed through works for the more or less complete removal of the impurities. The processes of treatment which have been thought most worthy of consideration in this connection are such as have been well established by experience. Screens are considered because of their compactness and ability to operate with varying quantities of sewage and small head. Settling basins have been included because of their almost universal employment in sewage purification works and their efficiency in removing suspended matter. Chemical precipitation has been considered because it is one of the most efficient means for removing both suspended and dissolved matter at one process. Sprinkling filters have been included, since they represent the most effective means of oxidizing the sewage impurities in a given area of land. It would be feasible, and it is customary where a high degree of purification is required, to combine two or more of these processes in a given plant.

The least effective process which seems worth considering for the sewage which is to be discharged into the harbor is screening, and the highest degree of purification practicable in most cases in the territory where the sewage is produced is screening and rapid settlement. More purification than this would require a greater amount of land than is procurable except at great cost and involve probable nuisance from odors and flies.

Estimates of the quantities of sewage discharged into New York harbor shows that all sections do not receive an equal share of pollution; the analyses of the water show that the circulation of the tide is insufficient to distribute satisfactorily the excessive burden which some sections receive. Some parts of the harbor are much more polluted than others, the region of greatest pollution being close to the most densely settled part of New York City. The Lower East river and Harlem receive large quantities of sewage from both shores.

TABLE XCVII

Volumes of Water at Low Tide in the Tidal Prism and the Net Discharge from the Several Divisions of the Harbor. The Quantities are Expressed as Million Cubic Feet.

Division of the Harbor	Volume of Water Below Mean Low Tide	Tidal Prism	Net Ebb Flow in 12 Lunar Hours
Harlem river	285	148	15
Hudson river, Battery to Mt. St. Vincent	12,330	1,697	1,087
Upper East river	5,512	1,869	....
Lower East river	4,174	552	100
Upper bay	12,970	2,541	1,283
Newark bay	1,542	1,071	105
Kill van Kull	728	150	88
Jamaica bay	2,258	2,307	....
	39,799	10,335	....

Table XCVII was prepared partly from tidal data computed by this commission and partly from information supplied by the United States Coast and Geodetic Survey in 1909 as a result of studies which were made in response to this commission's request.

It will be seen from Table XCVII that the Upper bay contains more water at low tide, has a larger tidal prism and has a larger net discharge of water than has any other part of the harbor. The Hudson river is a close second in volume at low tide, but it has a smaller prism and net flow than the Upper bay. The tidal prism and volume of water at low tide are nearly the same in Jamaica bay and Newark bay, from which it appears that these bodies of water are almost half renewed at each tide.

In the Lower East river, the tidal prism is one-sixth the volume of water which lies beneath the level of mean low tide and the net ebb flow is about one twenty-seventh of it. Nowhere else in the metropolitan district is the net ebb flow so small in comparison with the tidal prism or volume of water at low tide. Large as is the volume of water in this division, it is evident that there is not a great deal of new water passing through it. In the Harlem also, the tidal prism is large and the net ebb flow small when compared with the volume of water at mean low tide. From these figures, it appears that such refreshing action as the Lower East river and Harlem river receive is due to diffusion with cleaner water at the two ends of these streams and that little renewal occurs by actual displacement with water from a neighboring section. Large though the Lower East river seems to be and swift as are its currents, it has only one-tenth as much net ebb flow as the Hudson.

To facilitate computations which will be described later, the quantities of sewage discharged into the several divisions of the harbor have been converted from gallons per 24 hours to cubic feet per 12 lunar hours. The results are recorded in Table XCVIII.

TABLE XCVIII

VOLUME OF SEWAGE DIRECTLY TRIBUTARY TO THE SEVERAL DIVISIONS OF THE HARBOR.

Division of the Harbor	Directly Tributary Million Cu. Ft. per 12 Lunar Hours	
	Year 1910	Year 1940
Harlem river	6.9	17.5
Hudson river	9.2	20.9
Upper East river	1.5	6.9
Lower East river	17.1	31.5
Upper bay	4.4	8.2
Newark bay	0.9	2.1
Kill van Kull	0.5	1.6
Jamaica bay	3.7	11.3

TABLE XCIX

RATIOS OF THE VOLUME OF SEWAGE DIRECTLY TRIBUTARY PER 12 LUNAR HOURS TO THE VOLUME OF WATER IN THE HARBOR AT MEAN LOW TIDE. THE QUANTITIES GIVEN ARE IN MILLIONS OF CUBIC FEET.

Division of the Harbor	Water in the Division	Sewage Tributary to the Division			
		Year 1910		Year 1940	
		Volume	Ratio	Volume	Ratio
Harlem river	285	6.9	1:41	17.5	1:16
Hudson river	12,330	9.2	1:1350	20.9	1:590
Upper East river	5,512	1.5	1:3675	6.9	1:790
Lower East river	4,174	17.1	1:244	31.5	1:132
Upper bay	12,970	4.4	1:2920	8.2	1:1580
Newark bay	1,542	0.9	1:1680	2.1	1:740
Kill van Kull	728	0.5	1:1470	1.6	1:460
Jamaica bay	2,258	3.7	1:550	11.3	1:180
	39,799	44.2	1:900	100	1:398

Table XCIX, which is prepared from data contained in Tables XCVII and XCVIII, emphasizes the proportionately heavy sewage burden which is now, and in future would be, placed upon the Lower East river. The ratio of sewage to water at mean low tide which was 1 to 244 in 1910 would be 1 to 132 by 1940. A notably low ratio is that of the Kill van Kull which was 1 to 1470 in 1910 and would be 1 to 460 by 1940. This body of water received much of its pollution from neighboring bodies of water. The pollution of Newark bay will increase by direct contributions of sewage until the ratio which was 1 to 1680 in 1910 will be 1 to 740 by 1940 unless measures are taken to keep the sewage out of it.

TABLE C

RATIOS OF THE VOLUME OF SEWAGE DIRECTLY TRIBUTARY TO THE VOLUME OF WATER IN THE TIDAL PRISM. THE QUANTITIES GIVEN ARE IN MILLIONS OF CUBIC FEET.

Division of the Harbor	Water in the Prism	Sewage Tributary to the Division			
		Year 1910		Year 1940	
		Volume	Ratio	Volume	Ratio
Harlem river	148	6.9	1:21.4	17.5	1:8.5
Hudson river	1,697	9.2	1:185	20.9	1:81
Upper East river	1,869	1.5	1:1246	6.9	1:271
Lower East river	552	17.1	1:323	31.5	1:17.5
Upper bay	2,541	4.4	1:570	8.2	1:310
Newark bay	1,071	0.9	1:1170	2.1	1:510
Kill van Kull	150	0.5	1:300	1.6	1:94
Jamaica bay	2,309	3.7	1:540	11.3	1:175
	10,337	44.2	1:229	100.0	1:101

Table C has been prepared from Tables XCVII and XCVIII and shows the remarkably small ratios which exist between the sewage and tidal prism in most of the divisions of the harbor. The smallest occurs in the Harlem, 1 to 21.4, although the Lower East river, 1 to 32.3, is very low for the year 1910. In 1940 the tidal prism will be only 8½ times the volume of sewage discharged directly into the Harlem and in the Lower East river only 17½ times the quantity of sewage received.

Unlike the ratio of sewage to water below mean low tide, the relation of sewage to the tidal prism is comparatively large in Newark bay and will be considerable in 1940. This division of the harbor, which was comparable with the Lower East river in Table XCIX, resembles the Hudson river, where the pollution is, and probably will remain, large.

The quantities of water passing through each division in their relation to the volume of sewage directly discharged are shown by Table CI, which was prepared from Tables XCVII and XCVIII.

TABLE CI

RATIO OF THE VOLUME OF SEWAGE DIRECTLY TRIBUTARY PER 12 LUNAR HOURS TO THE NET EBB FLOW. THE QUANTITIES GIVEN ARE IN MILLIONS OF CUBIC FEET.

Division of the Harbor	Net Ebb Flow	Sewage Tributary to the Division			
		Year 1910		Year 1940	
		Volume	Ratio	Volume	Ratio
Harlem river	15	6.9	1:2.2	17.5	1:0.85
Hudson river	1,087	9.2	1:119	20.9	1:52
Upper East river	....	1.5	....	6.9	....
Lower East river	100	17.1	1:5.9	31.5	1:3.2
Upper bay	1,283	4.4	1:288	8.2	1:156
Newark bay	105	0.9	1:114	2.1	1:50
Kill van Kull	88	0.5	1:178	1.6	1:55
Jamaica bay	24	3.7	1:6.5	11.3	1:2.1
	2,702	44.2	1:61	100.0	1:27

The small amount of dilution from the net ebb flow which the sewage which was discharged into the Lower East river received in 1910 and will receive in 1940 is even more graphically indicated in this table than in its predecessors. By 1940 there will be more sewage discharged into the Harlem than there will be tidal water passing through that stream. There will be about three times as much tidal water as sewage passing out of the Lower East river. The Hudson river and Upper New York bay alone seem to be comparatively well supplied with water available for flushing purposes.

Table CII shows the number of tons of the various constituents of the sewage based on the composition shown in Table III, Part II, Chap. II, page 47 of this report, and the volume shown in Table XCVIII, page 504. It will be seen that in every important respect the Lower East river receives a greater weight of contaminating matters than does any other division of the harbor, irrespective of its size. Next comes the Hudson river, followed by the Harlem. The total weight of sewage materials discharged into the Kill van Kull and Newark bay is small as compared with the quantities of polluting matters discharged into the Lower East river.

TABLE CII

Solid, Organic and Volatile Matters Contained in the Sewage Directly Tributary to the Several Divisions of the Harbor. The Quantities are Expressed as Tons of 2,000 lbs. per 12 Lunar Hours.

Division of the Harbor	Year	Suspended Solid Matters	Organic and Volatile Matters					
			Total	Dissolved	Suspended	Nitrogenous	Fat, etc.	Carbon
Harlem river.......	1910	52	70	35	35	26	9	35
	1940	111	148	74	74	56	18	74
Hudson river.......	1910	65	87	43	44	33	11	43
	1940	126	168	84	84	63	21	84
Upper East river...	1910	12	16	8	8	6	2	8
	1940	43	57	29	28	21	7	29
Lower East river...	1910	133	178	89	89	67	22	89
	1940	209	279	139	140	105	35	139
Upper bay.........	1910	34	45	23	22	17	6	23
	1940	59	79	40	39	30	10	40
Newark bay........	1910	7	9	4	5	3	1	4
	1940	13	18	9	9	7	2	9
Kill van Kull.......	1910	3	4	2	2	2	0.6	2
	1940	9	12	6	6	4	2	6
Jamaica bay.......	1910	23	30	15	15	11	4	15
	1940	59	79	39	40	30	10	39
Total..........	1910	329	439	219	220	165	55.6	219
	1940	629	840	420	420	318	105	420

Table CIII, which has been prepared from Tables XCVI and XCVIII, shows the weight of sewage ingredients which will be discharged into the harbor in 1910 and 1940, assuming that the sewage is first passed through certain forms of treatment with the object of removing impurities. The efficiency of the treatment employed has been assumed as follows: The screens remove 15% of suspended matter and 10% of organic matter; sedimentation 60% of suspended matter and 30% of organic matter; chemical precipitation 85% of suspended matter and 50% of organic matter; sprinkling filters 90% of suspended matter and 70% of organic matter.

It will be observed that the use of any of these processes would be beneficial, but that the residue to be discharged after screening or sedimentation would still leave very large quantities of polluting matter to go into the water. Chemical precipitation and the use of sprinkling filters would probably furnish all the relief needed for as many years as can now be anticipated. As has been shown elsewhere in this report, however, these latter processes are not applicable unless the sewage is carried to some point far removed from its present source for treatment.

TABLE CIII

Suspended and Organic Matters which would be Contained in the Sewage Directly Tributary to the Several Divisions of the Harbor After Treatment. The Quantities Given are in Tons per 12 Lunar Hours.

Division of the Harbor	Year	Crude Sewage		Sewage After Treatment							
				Screens		Sedimentation		Chemical Precipitation		Sprinkling Filters	
		Sus.	Org.	Sus.	Org.	Sus.	Org.	Sus.	Org.	Sus.	Org.
Harlem river	1910	52	70	44	63	21	49	7.8	35	5.2	21
	1940	111	148	94	153	44	104	16.6	74	11.1	44
Hudson river	1910	65	87	55	78	26	61	9.8	44	6.5	26
	1940	126	168	107	151	50	118	18.9	84	12.6	50
Upper East river	1910	12	16	10	14	5	11	1.8	8	1.2	5
	1940	43	57	37	51	17	40	6.4	28	4.3	17
Lower East river	1910	133	178	113	160	53	125	20.0	89	13.3	53
	1940	209	279	178	251	84	195	31.4	140	20.9	84
Upper bay	1910	34	45	29	40	14	32	5.1	22	3.4	13
	1940	59	79	50	71	24	55	8.8	39	5.9	24
Newark bay	1910	7	9	6	8	3	6	1.0	4	0.7	3
	1940	13	18	11	16	5	13	2.0	9	1.3	5
Kill van Kull	1910	3	4	3	4	1	3	0.5	2	0.3	1
	1940	9	12	8	11	4	8	1.4	6	0.9	4
Jamaica bay	1910	23	30	20	27	9	21	3.4	15	2.3	9
	1940	59	79	50	71	24	55	8.8	40	5.9	24
Total	1910	329	439	280	394	132	308	49.4	219	32.9	131
	1940	629	840	535	755	252	588	94.3	420	62.9	252

CHAPTER IV

TIDAL CURRENTS IN NEW YORK HARBOR AS SHOWN BY FLOATS

RECORDS OF OBSERVATIONS FROM 1907 TO 1913, INCLUSIVE

Observations of harbor currents, as shown by floats, were described in the report of this commission dated April 30, 1910, Chapter IV, page 183, *et seq.,* and further studies in this direction were made in 1913. The object of the new work was to obtain knowledge of the currents in Lower New York bay, the immediate point of interest being the transporting effects to be expected upon the discharge of sewage from the proposed outlet island located about midway between Sandy Hook and Rockaway Point. The site of the island, the main channels and various lighthouses and buoys mentioned here are shown in Fig. 29.

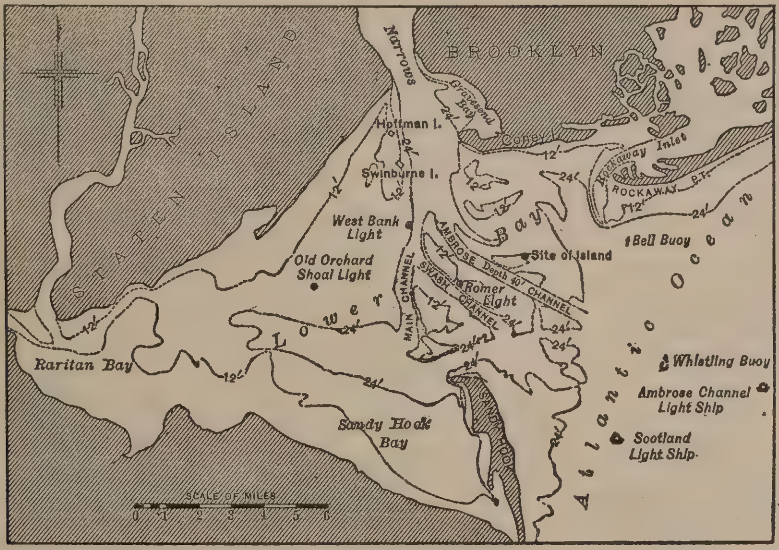


FIG. 29

In the report of 1910, the method of work done up to that time was described and the principal results of the float experiments were set forth. A large number of float observations which had been made at the time the 1910 report was prepared could not be given in detail and it has remained for the present to record these in their proper form.

Scope of Work

There are here described in the form of cuts all the float records made by the commission from 1907 to 1913. Each cut is a photographic reproduction of a carefully made outline map of the part of the harbor where the observations were carried on, with the path of the float and the essential data relating thereto plotted upon the map.

Method of Work in 1913

The observations were made from a boat chartered for the purpose. This boat was 62 feet long, 16-foot beam and drew 5 feet of water. Her tonnage was about 40 and she was propelled by a 30-h.p. steam engine; her speed averaged about 8 miles per hour. The boat carried a red flag, which proved an effective means of warning off traffic. The crew consisted of a captain, engineer and deckhand.

This steamer served its purpose acceptably. A large, open, forward deck covered by an awning afforded a convenient place for handling the floats and making the observations, while an unused galley under the pilot house afforded place for storage of instruments and equipment and permitted the setting up of a drawing board where the observations could be plotted. In a heavy sea or ground-swell the steamer rolled considerably, a tendency which was aggravated when drifting near the float. There were comparatively few occasions when the sea was too rough for operations.

The survey party consisted of two, and, at times, three assistants. Those engaged upon this work, which was done under the direction of the President, were Ernest F. Robinson, Herbert W. Harvey and Homer Calver. Their duty was to follow the course of the float, guard it from injury by passing vessels, determine its position at frequent

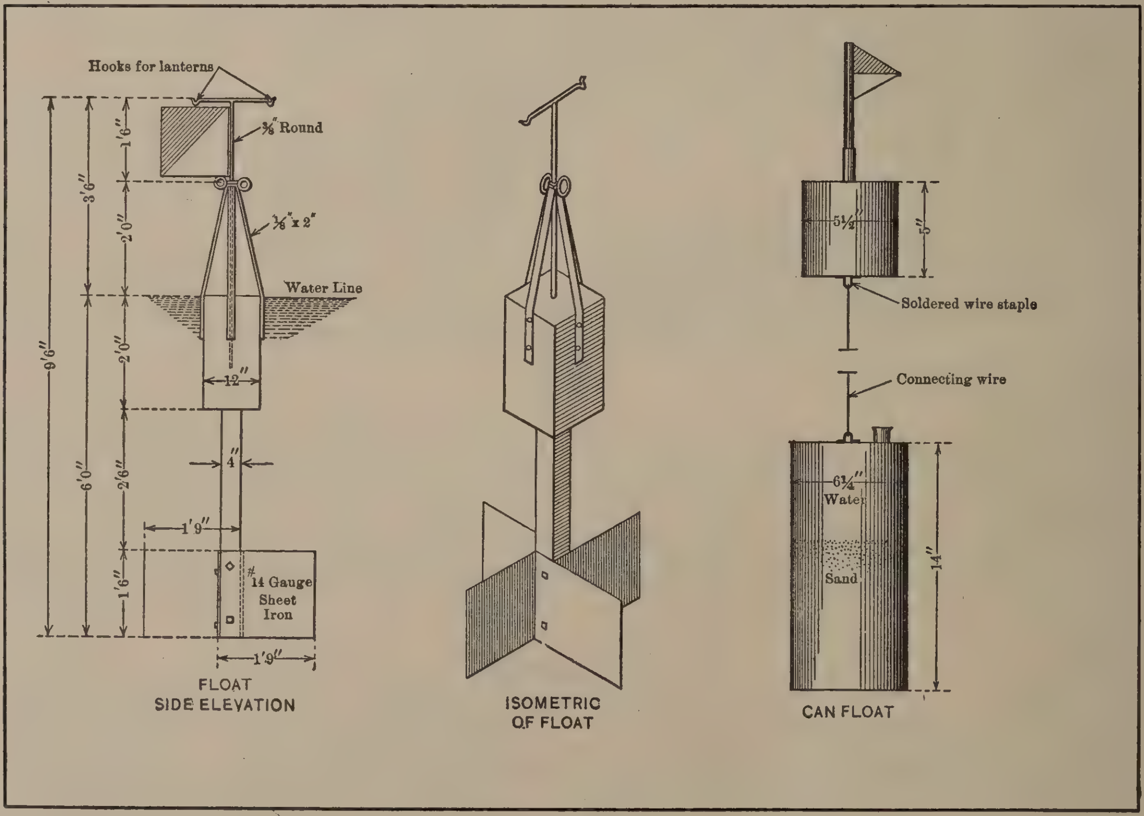


FIG. 30

intervals and plot the positions upon a standard chart of the U. S. Coast and Geodetic Survey.

FLOATS

The typical float used in the observations of 1913 was similar to the spar float described in the report of 1910. It is shown in Fig. 30. The stem was a piece of 4-inch by 4-inch timber, 6 feet long, around the upper end of which was built the float proper—a block of wood 12 inches by 12 inches by 24 inches. On the lower end of the stem were 4 vanes 21 inches by 18 inches, placed at right angle with one another and made of No. 14 gauge sheet iron. A ⅜-inch rod for carrying a flag by day or lanterns by night projected about 3½ feet above the top of the float; it was supported at its middle point by a frame of four ⅛-inch by 2-inch flat bars. At the top of this frame were placed two 3-inch rings for convenience in catching the float when removing it from the water.

This float, when in use, was submerged so that the top was about even with the surface of the water. No effect was observable from the wind. The flag and iron frame may have caught some wind, but not enough to appreciably affect the course of the float. When the wind was very fresh the boat was obliged to quit work on account of the seas, for which reason the float was never subjected to heavy wind pressure such as might have altered its course. It was noticed that floating objects which happened to be within view, such as blocks of wood, were easily driven by the wind, as was the steamer, while the float often traveled in an opposite direction.

The flag carried by the float was square, diagonally divided into red and white, and was plainly visible at distances of a quarter of a mile or more. No difficulty was ever experienced in finding the float. All the observations were made during daylight hours. The flags carried by the float and attending observation steamer were always scrupulously respected by passing vessels, most of the large ocean liners slowing down or stopping their engines in passing. The number of ships which showed the work this courtesy was large, most of the observations being carried on in the most frequented channel between New York harbor and the open ocean.

None of the floats approached the shore, or grounded or went into inaccessible places. They were never injured by vessels and throughout the work no repairs were required beyond an occasional straightening of the flag rod at the top, due to accidents in handling.

Can floats were used for a part of the time to determine the trend of currents at other depths than indicated by the wooden floats. The construction of the can floats has been shown in the 1910 report of the commission. Fig. 30, page 502, shows the design and dimensions of both spar and can floats.

The can float was in two parts connected by wire, whose length could be regulated so as to suit the depth of water under observation. One can floated at the surface and supported the other can. Each was filled with sand and water sufficiently to be submerged. The can floats were not found serviceable in the rough water of Lower New York bay. The choppy seas would raise and lower the upper can, while the lower can could not accommodate itself to these sudden motions. The result was a series of jerks upon the connecting wire which tore out the fastenings. Occasionally the can floats grounded unexpectedly or dragged upon the bottom.

By watching for favorable opportunities some observations of interest were made by means of the can floats in spite of the shortcomings which have been mentioned.

Unsuccessful Attempts to Use Current Meters

Efforts were made to use current meters to determine the force and direction of currents at different depths at the site of the proposed island and elsewhere, but this undertaking was not successful, owing, apparently, to the difficulties of insulation brought about by salt water conditions.

The efforts extended over the period between August 18 and September 3, 1913. Two current meters were obtained by loan through the courtesy of the Dock Department of the City of New York, one being of the Ellis type and the other of the large Price type. The engineers of the Dock Department had been unable to obtain satisfactory results from their use.

The meters were thoroughly overhauled and some changes made in their insulation in order to avoid the difficulties anticipated. Preliminary to making observations, the meters were carefully rated. For this purpose a course of 600 feet was laid off along the bulkhead in Sheepshead bay and ranges at right angles at the ends and center of this course were set up. The meters were placed at the lower ends of two vertical spars, one rigged over each bow and far enough outboard to clear the bow wave. The spars were braced and guyed so as to maintain a vertical position and keep the meters submerged about 1½ feet.

The electrical connections were led inboard to a pair of telephone head receivers, one for each meter, which carried the grating sound of the contact of each revolution of the meter wheel to the ear of the observer. The number of revolutions which occurred at various speeds of the boat when passing over the measured course were counted and the time determined by stop-watches. The revolutions of time were reduced to revolutions per second and the speed of the boat reduced to feet per second. Upon a sheet of cross-section paper the feet per second were then plotted as abscissas and the corresponding revolutions per second as ordinates. The points plotted at the intersection of these co-ordinates lay close to a straight line. This was the rating curve of the meter.

It was intended that the meters should be observed by lowering them just below the surface of the water in the time taken for 10 revolutions. For bottom velocities the meter was to be lowered to the bottom and then raised a foot when a second reading was taken. Mid-depth reading was also to be obtained.

Trouble with the insulation occurred with both meters, but the Price meter seemed to be the stronger and more serviceable of the two and was more easily examined and repaired. In the Ellis meter the trouble from insulation was due largely to the fact that sea water would enter the contact chamber, displacing the paraffine oil with which it was filled, and short-circuit the meter. The entrance was effected around the axle, where it entered the contact box, there being considerable play at this point. The fine wire spring, upon which the contact depended, seemed subject to some electrolytic action by which it was eaten away, necessitating frequent renewals with copper wire. In spite of every effort which could be made, this difficulty could not be overcome. Continual repairing was necessary and fully 75 per cent. of the time was occupied in this work. It was impossible to determine what observations were accurate.

The Price meter gave trouble at first, owing to faulty insulation where the wire entered the contact chamber. The whole connection was finally covered bodily with paraffine, held in place by rubber insulating tape. The contact apparatus itself gave no trouble, when the chamber was kept filled with paraffine oil.

The chief difficulty with the Price meter occurred in the wire cable which was used to suspend the apparatus and carry the sound of the revolutions to the observer's ear. The cable stretched and opened up the insulation. This difficulty might have been overcome by providing a different method of suspension, but the prospect of further difficulties prevented this change being made.

In all, five attempts were made to secure observations for a complete tidal cycle. In only one case, that of August 29, was a record of any considerable duration obtained. This extended from 7:20 A. M. to 3:00 P. M., interrupted by frequent breakdowns. The observers were uncertain of the results. Short circuits, such as were continually occurring, produced in the head receivers a noise so closely resembling that of a contact of the meter that confusion resulted. The work was discontinued owing to the unreliability of the results and the probability that a large amount of time would necessarily be consumed in adjusting the meters to the work.

To obtain satisfactory results with current meters in such work as that contemplated new instruments should be provided, preferably of large Price type. Suitable changes should be made in the insulation to fit them for salt water; special cables should be provided for the suspensions and each observer should be supplied with a kit of proper tools and equipment for making hasty repairs in the field.

Collection of Data

As far as practicable the observations were begun just before the beginning of an ebb or flood current and continued throughout the succeeding flow of tide. As soon as the float was set adrift it was located by two sextant angles read from the steamer to three of the various lighthouses in the vicinity of the Lower bay. At intervals of half an hour, or 15 minutes near slack water, the steamer was run alongside the float and the location again determined, until the final location at the end of the observations, when the float was taken up.

Most of the courses started from the site of the proposed outlet island, whose location had been fixed from soundings on the Coast Survey charts. This location was determined in the field by trial, reading sextant angles from various positions of the boat until when plotted they indicated the required point. Ranges were then fixed in order that the point might readily be found again.

A tall stack on Sandy Hook was found to be on line with a notch in the skyline of Atlantic Highlands and, similarly, Norton's Point was on a line with a break in the skyline of Staten Island.

Through the courtesy of Col. S. W. Roessler, Corps of Engineers, U. S. A., a tripod was located as near the site of the proposed island as practicable by Mr. G. E. Balch, U. S. Assistant Engineer in charge of the Hydrographic Survey of the U. S. Engineer Corps in this vicinity. On attempting to locate the tripod at the site proposed it was found that the depth of water was somewhat in excess of that shown on the chart, so that the tripod could not conveniently be fixed exactly in the desired position. It was finally placed about 1,400 feet southwest of the proposed site in 13 feet of water at mean low tide. The Coast Survey chart shows a depth of 10 feet at this point. The tripod was constructed of 4-inch gas pipe and stood 36 feet high, about half this height being submerged.

The work was directed from the office in accordance with information mailed to headquarters at the close of each day's run. For this purpose an approximate drawing of the course last observed was made upon a small white print of the Lower bay with a scale of 1 to 80,000 and sent by mail. This sheet, in addition to recording the approximate path of the float, contained such information regarding the wind and weather conditions, hours of observation and tidal actions as might be necessary for a correct understanding of the work. On those occasions when the conditions were not favorable for observations the observers reported at the office for instructions.

Plotting the Data

The path followed by a float was laid down upon charts traced from the U. S. Coast and Geodetic Survey charts. The observations of the floats which were made at intervals of half an hour or more frequently permitted a series of points to be plotted, and when these were connected the path of the float was considered to have been determined.

Two sextant angles had been read in quick succession to three prominent landmarks whose position was located on the chart. In plotting the position of the float, the two adjacent angles were laid out on a piece of tracing cloth and this was shifted upon the chart until the three lines passed through the three station points. The intersection of the angles was then pricked through to the chart. The chart upon which the plotting was done had a scale of 1 to 40,000. Confusion among courses was avoided by using a fresh chart after three or four days' work.

The charts with the paths of the floats carefully plotted thereon were delivered at the commission's office and the records were transferred to separate sheets for reproduction.

There was determined for each float the total time and distance traveled, the average velocity and maximum velocity. The most important information was obtained from a study of the path itself. This was accepted as showing the trend of the main surface currents at the times and under the circumstances which occurred. In the cuts accompanying this report will be found all the essential data represented in graphic form.

Results

Twenty-five spar float observations were made in 1913. They were all made, entirely or in part, in Lower New York bay. They were begun on June 9, 1913, and finished August 25, 1913. The total number of hours worked was 341. From the beginning until about June 25 observations were made daily. Later, in order to obtain longer records, two days' work were concentrated in one, the work continuing through a complete tidal cycle when the conditions permitted. Interruptions to long-continued observations were frequent because of the scarcity of days upon which three successive slack waters occurred during daylight hours and because of fog and wind which not infrequently cut short or prevented observations being made after the party had been assembled and reached the point in the boat from which observations were to begin. The longest series of observations lasted 16 hours. They were on June 26 and July 22. There were 10 series of observations continued for 12 hours or more.

Of the 25 series of observations, two were made solely with a view to determine the time of slack water at the site of the proposed island as compared with the time of high and low water at Sandy Hook, and were not productive of any information as to the trend of the currents. Four others were cut short by fog, heavy weather or other unfavorable conditions; of these 3 did not progress far enough to afford useful information. There were thus left about 20 records capable of affording useful data.

The most striking characteristic of the records, considered as a whole, is the fact that the currents in the middle of Lower New York bay run parallel to the Ambrose channel and follow its turns at the upper end. This fact is established by a number of float records and is controverted by none. Another salient characteristic of the float paths is their avoidance of Jamaica bay and Coney island channel. A float carried well into the bight of Gravesend bay on the flood tide would return into the main channel and go down Ambrose channel instead of floating ashore on Coney island or following along the Coney island channel. This was undoubtedly due to the effect of the water in the tidal prism leaving Gravesend bay.

A tendency to continue down the old Main Ship channel instead of turning out to sea through Ambrose channel was marked in some floats leaving the Narrows. These floats were all halted by slack water near West Bank or Romer Shoals lighthouses. Other floats dropped at these points on the first of the flood, either turning north toward the Narrows or went into Raritan bay. In the former case they were likely to turn near Swinburne or Hoffman island and go out by Ambrose channel or return to West Bank light. In the latter case, a float would go into Raritan bay only to Old Orchard light or a little further and return on the next ebb current. One float released off Sandy Hook at slack water went almost due west for about four miles on the flood current and then returned to a point near the starting place.

Floats which were set adrift near Rockaway inlet bell buoy passed the inlet, showing no tendency to enter either on the flood or on the returning ebb current. Furthermore, floats carried out to sea on the ebb current in a line parallel to Ambrose channel returned in the same line, showing no tendency to move toward Rockaway beach or inlet.

The greatest distances traveled from the site of the proposed island on the flood and ebb currents respectively were to the Narrows and to Ambrose channel lightship when the start was made from the site at slack water. A float reaching the Narrows and returning parallel to Ambrose channel was carried further out than the starting point, and floats carried to sea, beyond the whistling buoy, never reached the entrance to Ambrose channel on the return flood tide.

From observations made with can floats it appeared that the deeper currents traveled more slowly than the currents near the surface and that the currents at the very top of the water moved more rapidly than any others. The difference was least between the route followed by the shallow can float and that of the wooden spar float, the difference amounting to 150 feet in 30 minutes. The deep can float lagged behind the wooden spar float between 800 and 1,000 feet in the same time.

CONCLUSIONS

Among the most important inferences to be drawn from the observations of spar floats in the Lower New York bay in the summer 1913 are the following:

1. The shores of Lower New York bay would be in no danger of pollution if sewage was to be discharged at the site of the proposed island.

2. On flood currents floating sewage would seldom, if ever, reach the Narrows and would not pass into the Upper bay.

3. There is no set of tidal water capable of carrying sewage from the site of the proposed island toward Rockaway beach or inlet nor towards Coney island on flood or ebb currents.

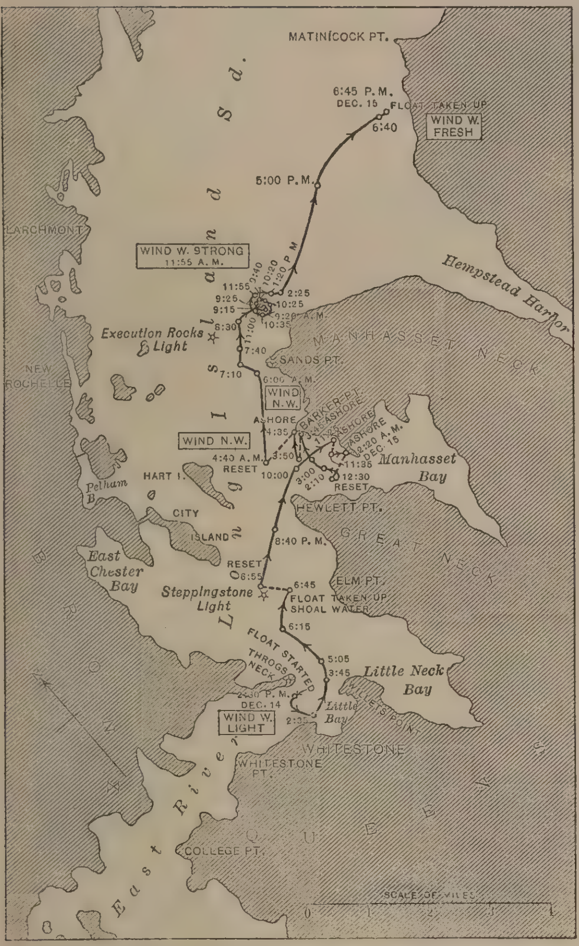
4. There is a resultant motion seaward from the vicinity of the proposed island and particles carried out to the whistling buoy or further will not return.

5. Floating particles will be repelled from Gravesend bay.

6. Little sewage, if any, will cross Ambrose channel, and that which does cross will proceed outward from the Narrows on the ebb current and will have a tendency to return by the same route.

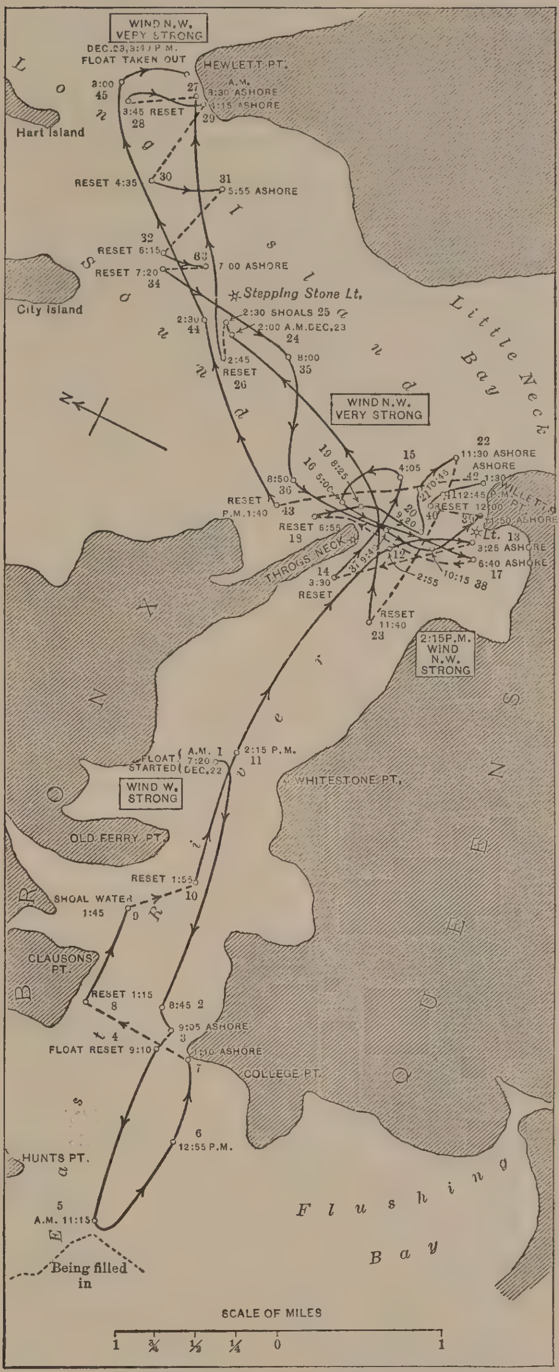
7. The proportion of sewage from the island which is capable of reaching Raritan bay is small and has no tendency to remain in the bay.

THE FLOAT RECORDS



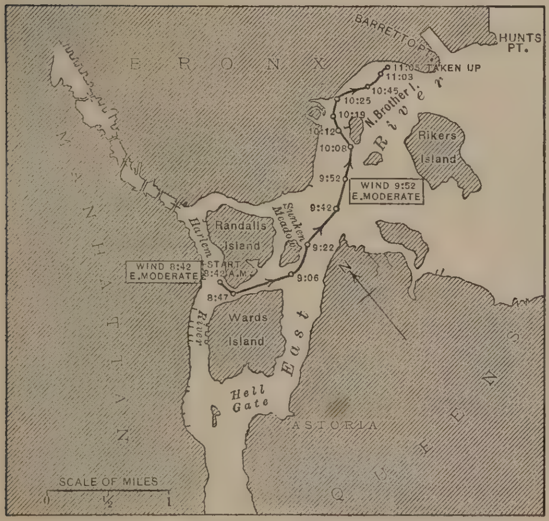
FLOAT 60, DEC. 14-15, 1909

Total distance, flood, = 14.43 miles in 26.58 hours
Average velocity .... = 0.54 miles per hour
Maximum " .... = 2.00 " " "



FLOAT 64, DEC. 22-23, 1909

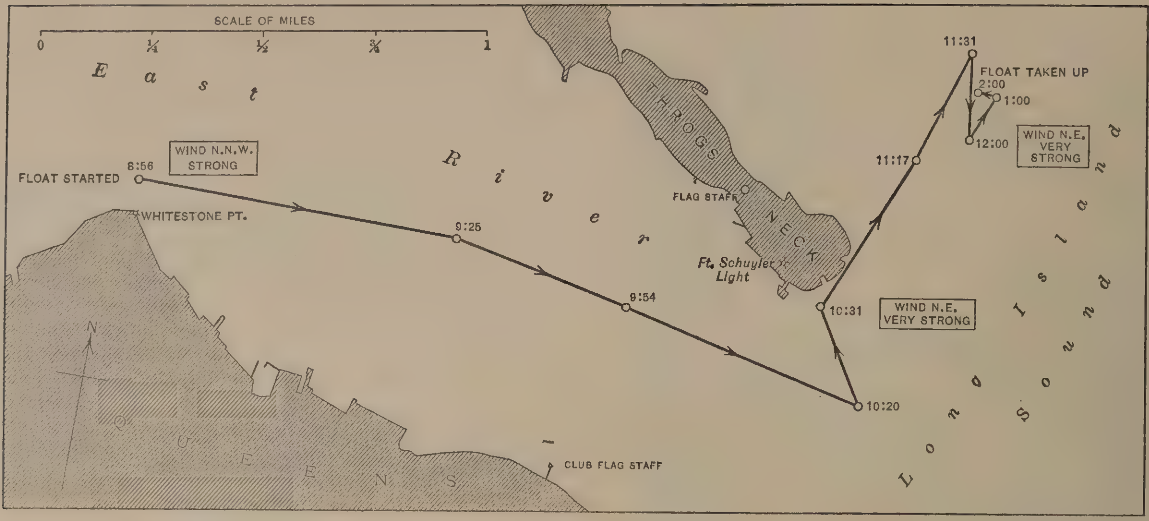
Total distance, flood, = 13.2 miles in 15.5 hours
Average velocity .... = 0.85 miles per hour
Maximum " .... = 2.32 " " "
Total distance, ebb, = 8.53 miles in 14.33 hours
Average velocity .... = 0.60 miles per hour
Maximum " .... = 1.16 " " "



FLOAT 15, AUG. 29, 1908

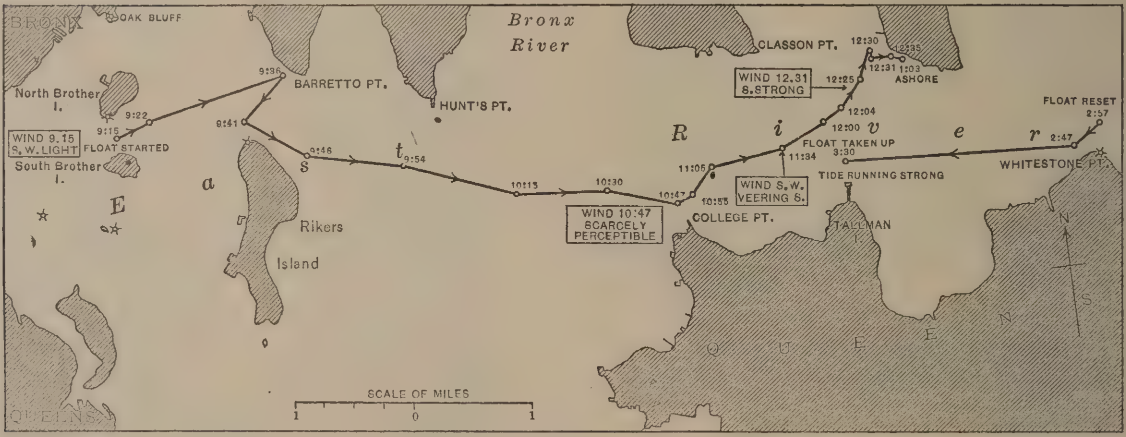
Total distance, flood, = 2.87 miles in 2.38 hours
Average velocity .... = 1.21 miles per hour
Maximum " .... = 2.55 " " "

Paths of Floats in the East River



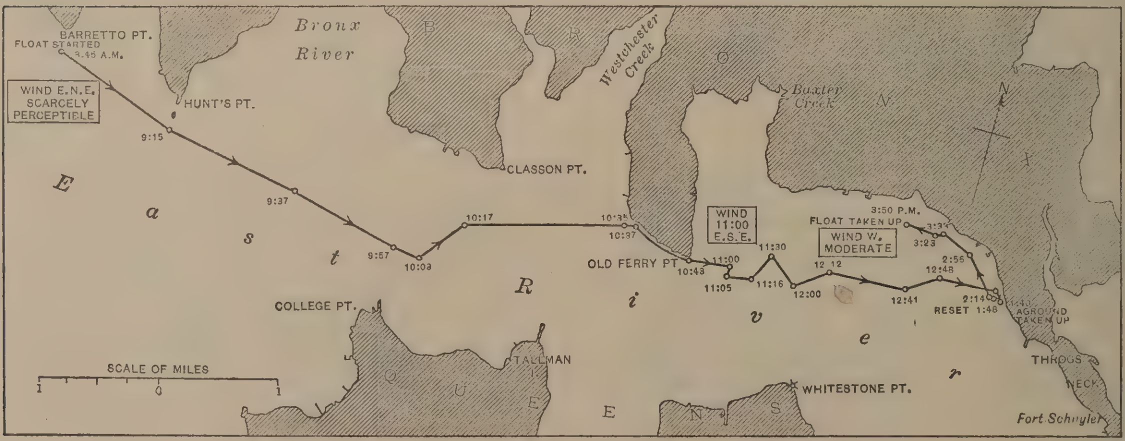
FLOAT 19, SEPT. 3, 1908

Total distance, flood, =**2.95** miles in **4.07** hours
Average velocity.... =**0.73** miles per hour
Maximum " .... =**1.51** " " "



FLOAT 17, SEPT. 1, 1908

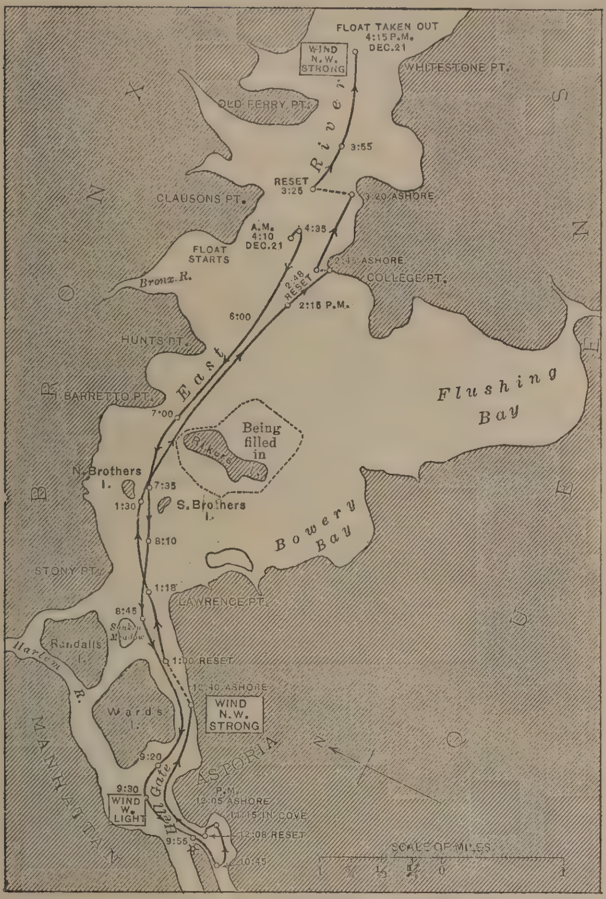
Total distance, flood, =**4.14** miles in **3.8** hours
Average velocity.... =**1.09** miles per hour
Maximum " .... =**3.60** " " "



FLOAT 18, SEPT. 2, 1908

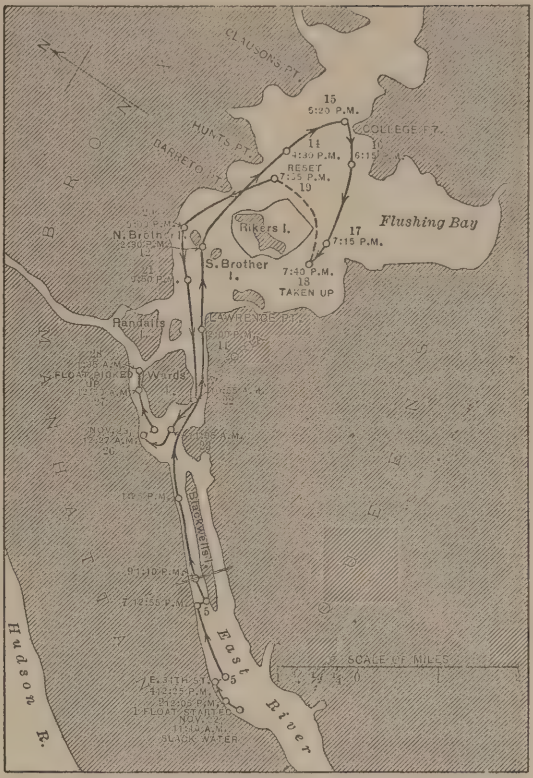
Total distance, flood, =**4.41** miles in **4.92** hours
Average velocity.... =**0.9** miles per hour
Maximum " .... =**1.93** " " "

Paths of Floats in the East River



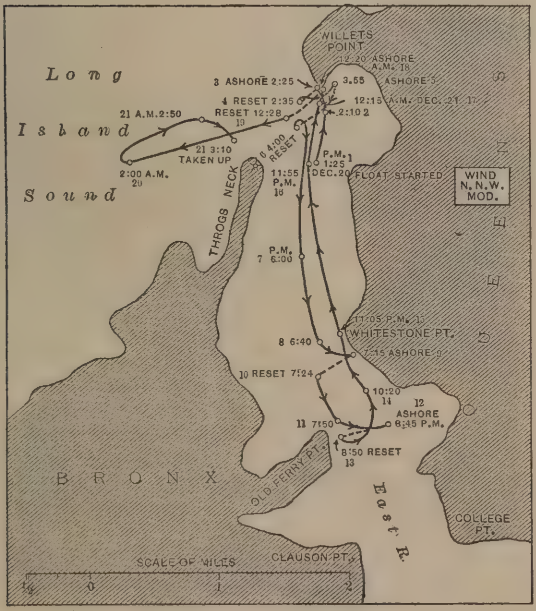
FLOAT 63, DEC. 21, 1909

Total distance, flood, =7.26 miles in 5.0 hours
Average velocity.... =1.45 miles per hour
Maximum " .... =2.36 " " "
Total distance, ebb, =6.00 miles in 6.17 hours
Average velocity.... =0.97 miles per hour
Maximum " .... =2.23 " " "



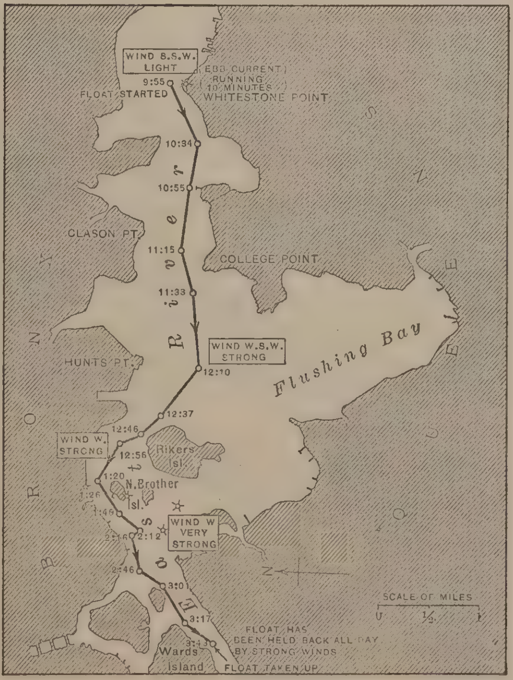
FLOAT 53, NOV. 22-23, 1909

Total distance, flood, =8.21 miles in 5.67 hours
Average velocity.... =1.45 miles per hour
Maximum " .... =4.12 " " "
Total distance, ebb, =6.31 miles in 6.87 hours
Average velocity.... =0.92 miles per hour
Maximum " .... =2.65 " " "



FLOAT 62, DEC. 20-21, 1909

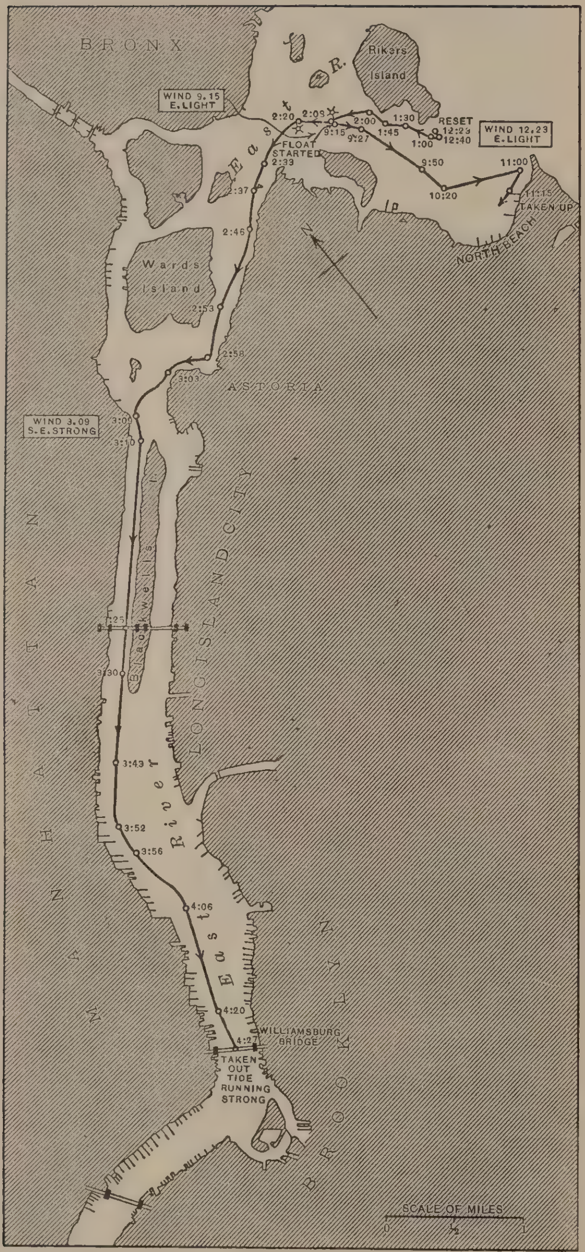
Total distance, flood, =5.40 miles in 7.33 hours
Average velocity.... =0.74 miles per hour
Maximum " .... =1.62 " " "
Total distance, ebb, =4.0 miles in 5.75 hours
Average velocity.... =0.70 miles per hour
Maximum " .... =0.97 " " "



FLOAT 25, SEPT. 10, 1908

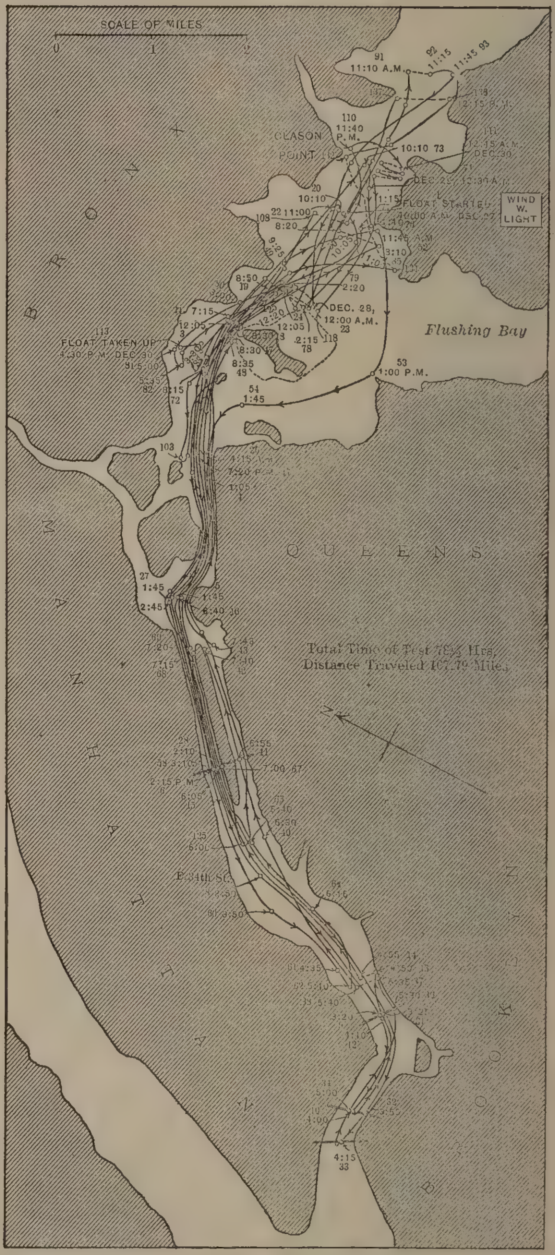
Total distance, ebb, =6.85 miles in 5.80 hours
Average velocity.... =1.18 miles per hour
Maximum " .... =1.98 " " "

Paths of Floats in the East River



FLOAT 16, AUG. 31, 1908

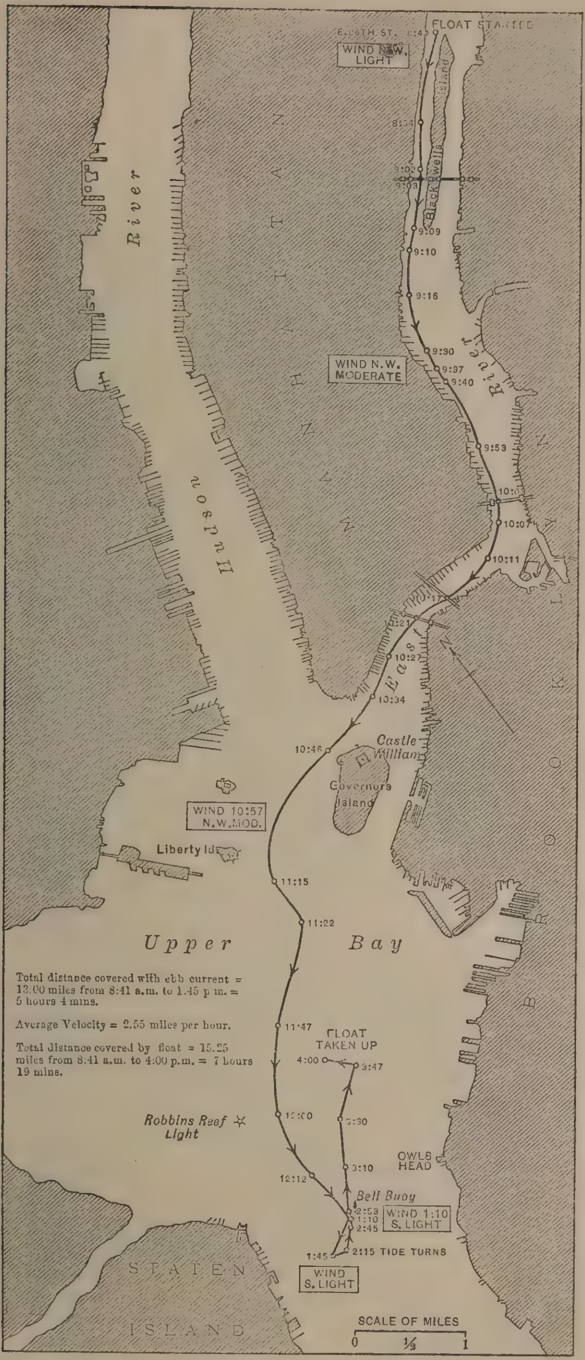
Total distance, ebb, =4.71 miles in 3.78 hours
Average velocity .... =1.25 miles per hour
Maximum " .... =5.52 " " "


SCALE OF MILES
0
1
2
BRONX
CLASON POINT
FLOAT STARTED 10:00 A.M. DEC. 27
WIND W. LIGHT
DEC. 28, 12:00 A.M.
FLOAT TAKEN UP 4:30 P.M. DEC. 30
Flushing Bay
QUEENS
MANHATTAN
BROOKLYN
Total Time of Test 78½ Hrs.
Distance Traveled 107.79 Miles.

FLOAT 65, DEC. 27-30, 1909

Total distance, flood, =51.86 miles in 37.25 hours
Average velocity .... = 1.39 miles per hour
Maximum " .... = 5.00 " " "
Total distance, ebb, =55.93 miles in 41.25 hours
Average velocity .... = 1.35 miles per hour
Maximum " .... = 5.37 " " "

Paths of Floats in the East River



Total distance covered with ebb current = 13.00 miles from 8:41 a.m. to 1.45 p m. = 5 hours 4 mins.

Average Velocity = 2.55 miles per hour.

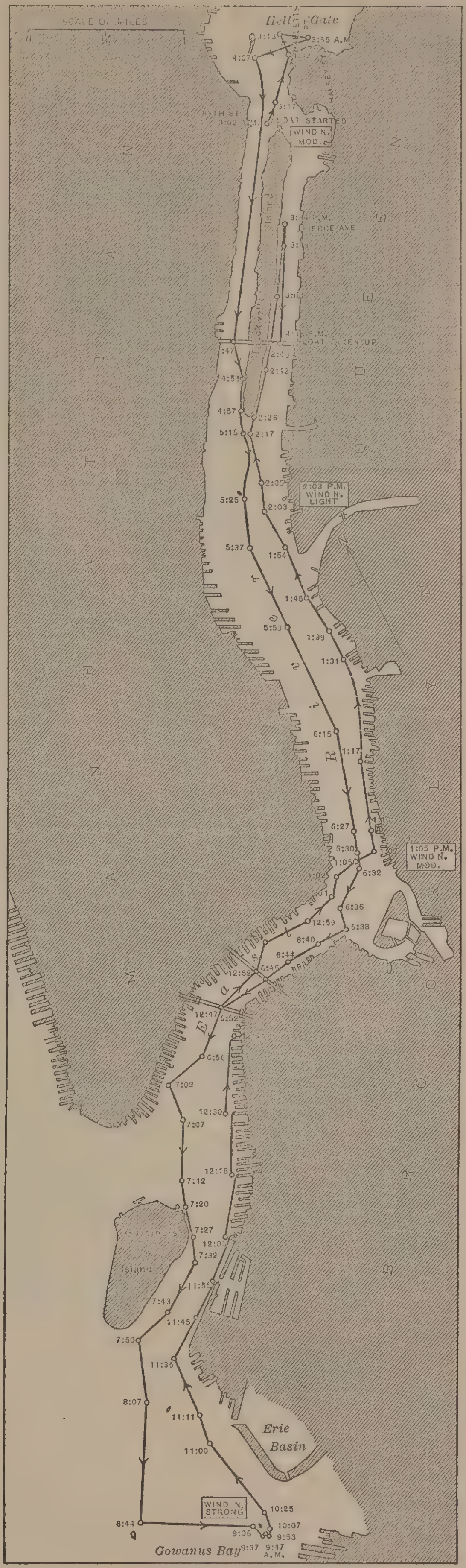
Total distance covered by float = 15.25 miles from 8:41 a.m. to 4:00 p.m. = 7 hours 19 mins.

FLOAT 23, SEPT. 8, 1908

Total distance, flood, = 2.25 miles in 2.25 hours
Average velocity.... = 1.0 mile per hour
Maximum " .... = 1.8 miles " "
Ebb, maximum velocity............ = 5.5 " " "

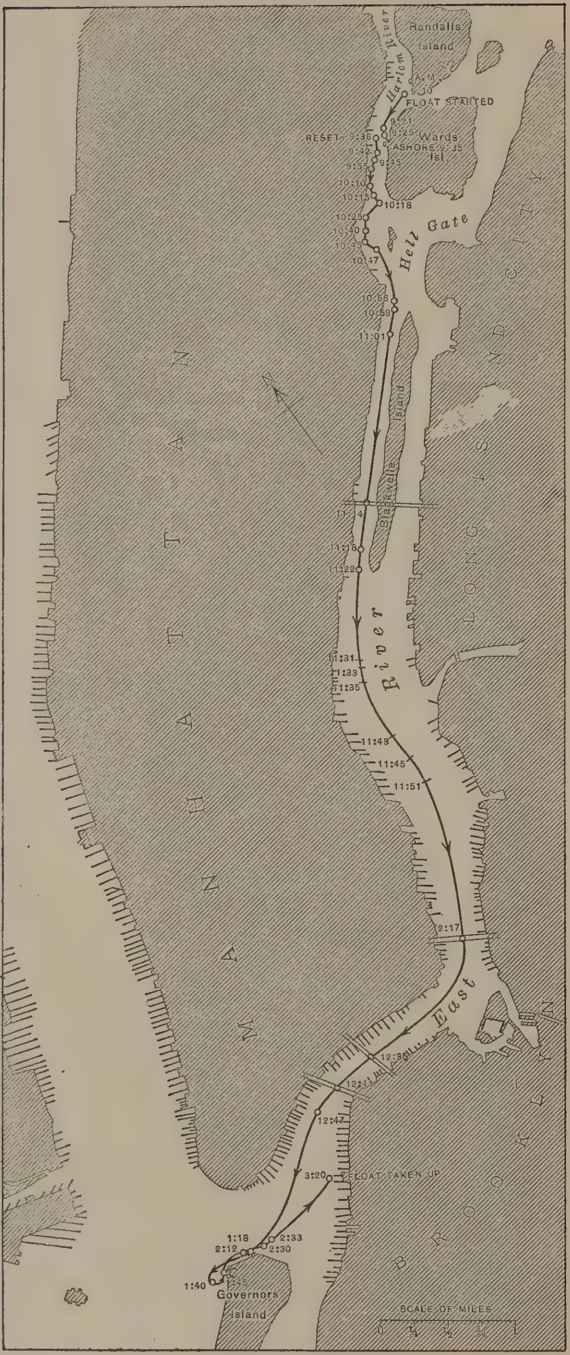
FLOAT 38

Total distance, flood, = 8.80 miles in 5.92 hours
Average velocity.... = 1.49 miles per hour
Maximum " .... = 7.20 " " "
Total distance, ebb, = 11.05 miles in 5.7 hours
Average velocity.... = 1.94 miles per hour
Maximum " .... = 5.70 " " "



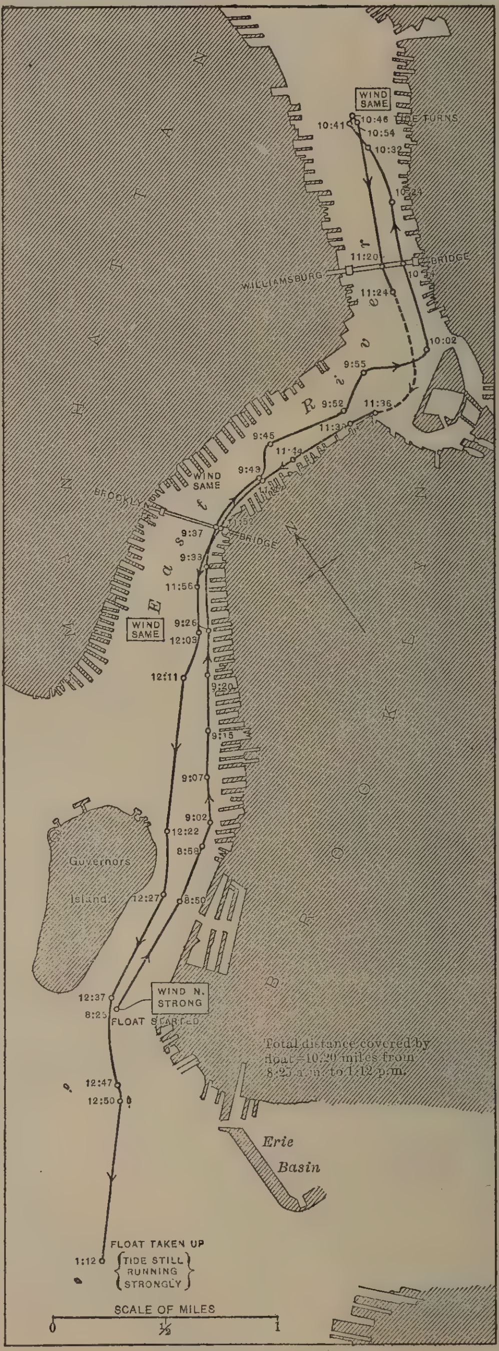
FLOAT 38, OCT. 3, 1908

Paths of Floats in the East River and Upper Bay



FLOAT 10, AUG. 24, 1908

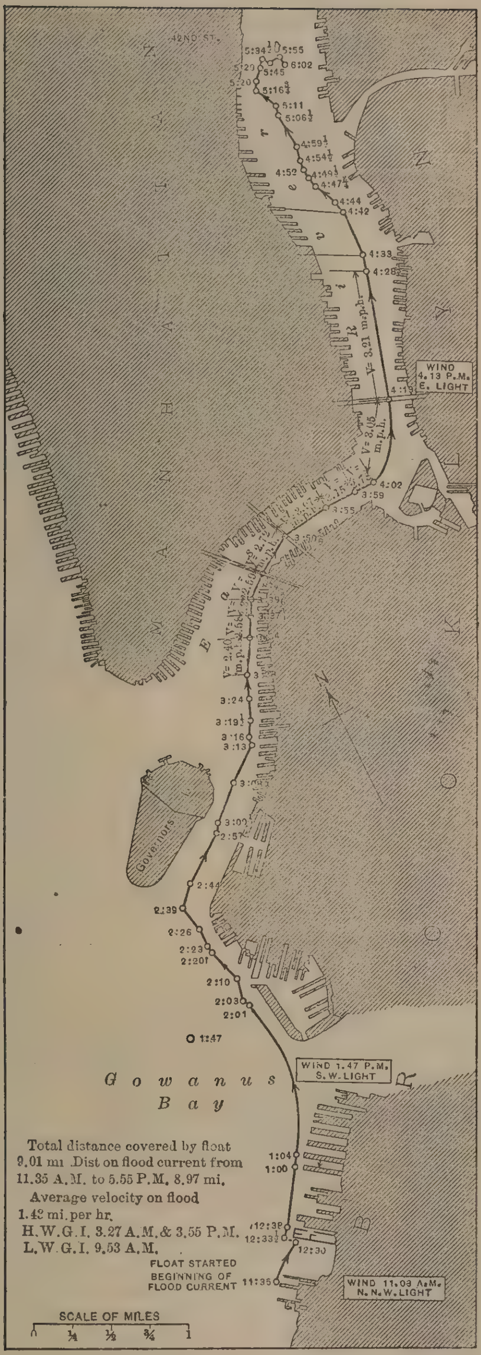
Total distance, ebb, =9.70 miles in 4.5 hours
Average velocity.... =2.15 miles per hour
Maximum " .... =6.00 " " "



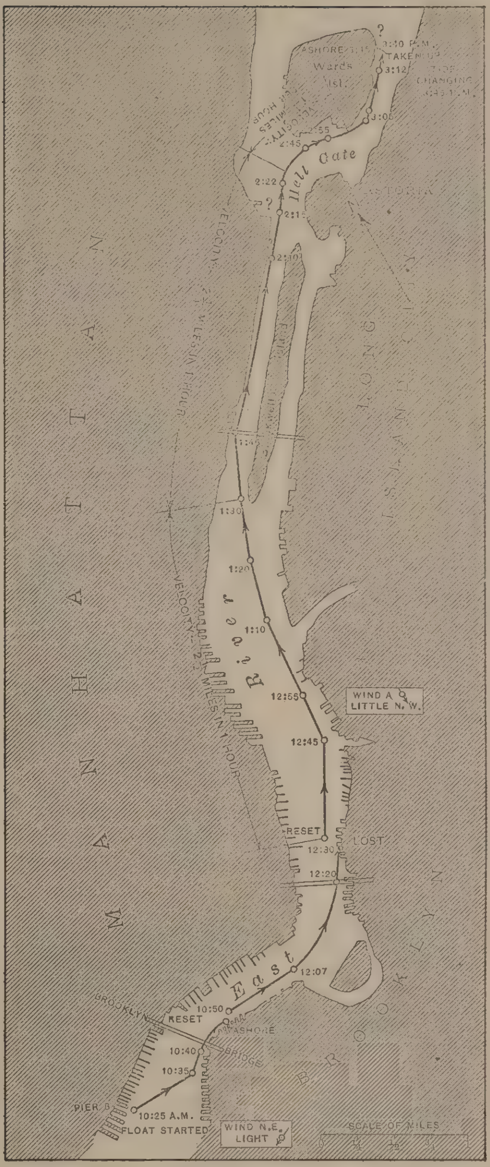
FLOAT 27, SEPT. 12, 1908

Total distance, flood, =4.60 miles in 2.35 hours
Average velocity.... =1.96 miles per hour
Maximum " .... =3.53 " " "
Total distance, ebb, =5.60 miles in 2.47 hours
Average velocity.... =2.27 miles per hour
Maximum " .... =4.03 " " "

Paths of Floats in the East River and Upper Bay

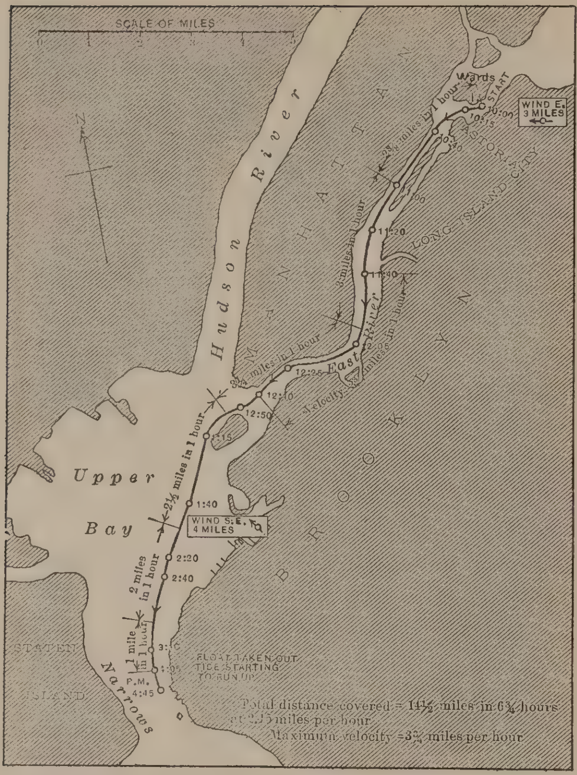

42ND ST.
5:55
6:02
5:45
5:20
5:11
4:52
4:44
4:42
4:33
4:28
WIND 4.13 P.M. E. LIGHT
V=3.21 m.p.hr
4:02
3:59
3:55
3:24
3:16
3:13
3:00
2:57
2:44
2:39
2:26
2:23
2:20
2:10
2:03
2:01
1:47
Governors
WIND 1.47 P.M. S.W. LIGHT
Gowanus Bay
Total distance covered by float 9.01 mi. Dist on flood current from 11.35 A.M. to 5.55 P.M. 8.97 mi.
Average velocity on flood 1.42 mi. per hr.
H.W.G.I. 3.27 A.M. & 3.55 P.M.
L.W.G.I. 9.53 A.M.
1:04
1:00
12:38
12:33
12:30
FLOAT STARTED BEGINNING OF FLOOD CURRENT 11:35
WIND 11.08 A.M. N.N.W. LIGHT
SCALE OF MILES
0 ¼ ½ ¾ 1
MANHATTAN
East River
BROOKLYN

FLOAT 39, OCT. 5, 1908
Maximum velocity, flood, =3.97 miles per hour



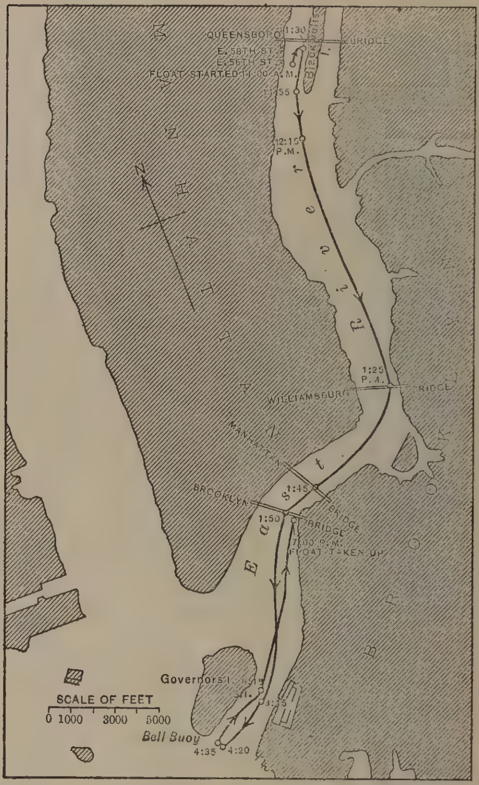
FLOAT F, MAR. 7, 1907
Total distance, flood, =8.0 miles in 4.78 hours
Average velocity.... =1.67 miles per hour
Maximum " .... =2.5 " " "

Paths of Floats in the East River and Upper Bay



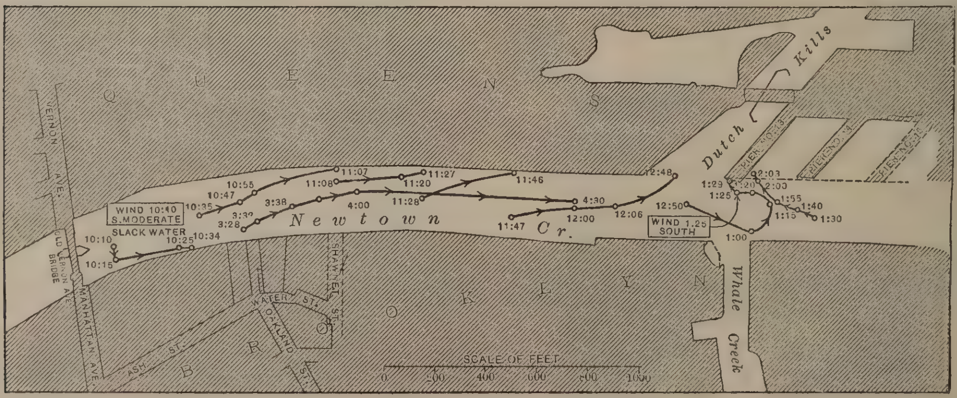
FLOAT L, MAR. 29, 1907

Average velocity, ebb, = 2.15 miles per hour



FLOAT 43, NOV. 15, 1909

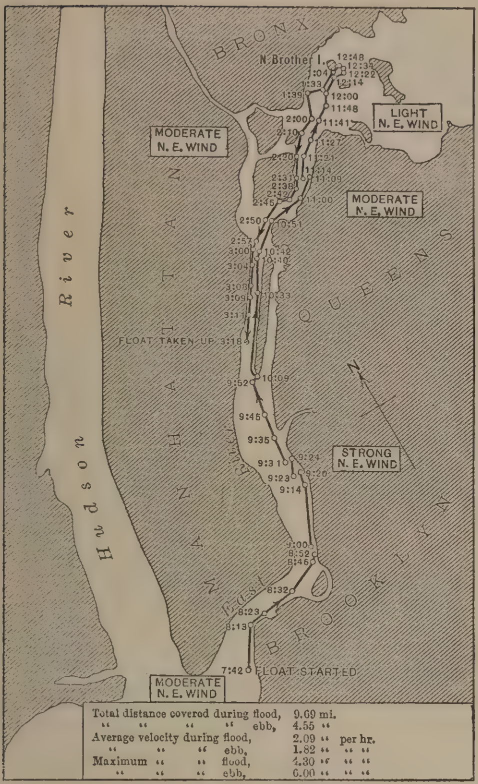
Total distance, flood, = 2.15 miles in 2.67 hours
Average velocity.... = 0.81 miles per hour
Maximum " .... = 2.05 " " "
Total distance, ebb, = 6.82 miles in 4.83 hours
Average velocity.... = 1.41 miles per hour
Maximum " .... = 4.00 " " "



FLOAT 22, SEPT. 5, 1908

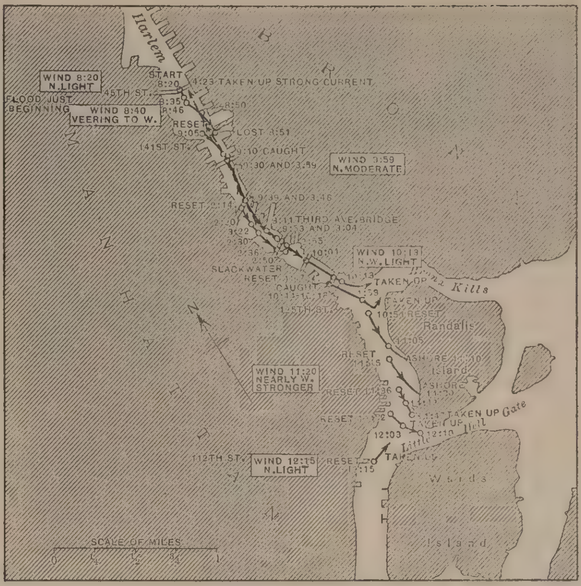
Total distance, flood, = 0.77 miles in 4.01 hours
Average velocity.... = 0.19 miles per hour
Maximum " .... = 0.33 " " "

Paths of Floats in the East River and Upper Bay



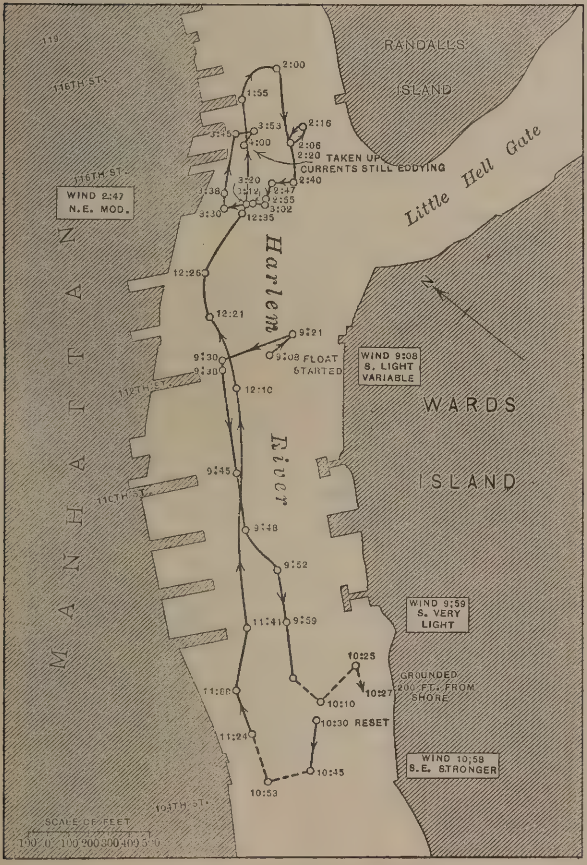
Total distance covered during flood, 9.69 mi.
" " " " ebb, 4.55 "
Average velocity during flood, 2.09 " per hr.
" " " ebb, 1.82 " " "
Maximum " " flood, 4.30 " " "
" " " ebb, 6.00 " " "

FLOAT 36, SEPT. 30, 1908



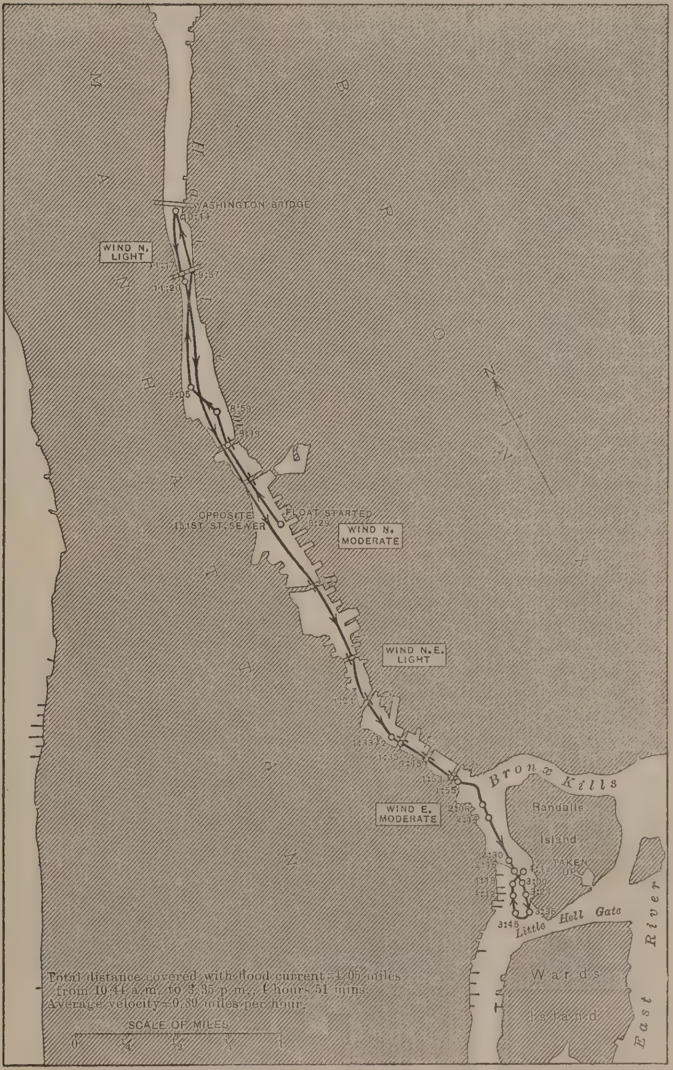
FLOAT 6, AUG. 18, 1908

Total distance, flood, = 2.75 miles in 6.52 hours
Average velocity . . . . = 0.42 miles per hour
Maximum " . . . . = 0.77 " " "
Total distance, ebb, = 0.84 miles in 1.47 hours
Average velocity . . . . = 0.57 miles per hour
Maximum " . . . . = 1.33 " " "



FLOAT 9, AUG. 21, 1908

Total distance, flood, = 0.74 miles in 3.12 hours
Average velocity . . . . = 0.24 miles per hour
Maximum " . . . . = 1.24 " " "
Total distance, ebb, = 0.74 miles in 3.03 hours
Average velocity . . . . = 0.24 miles per hour
Maximum " . . . . = 0.87 " " "

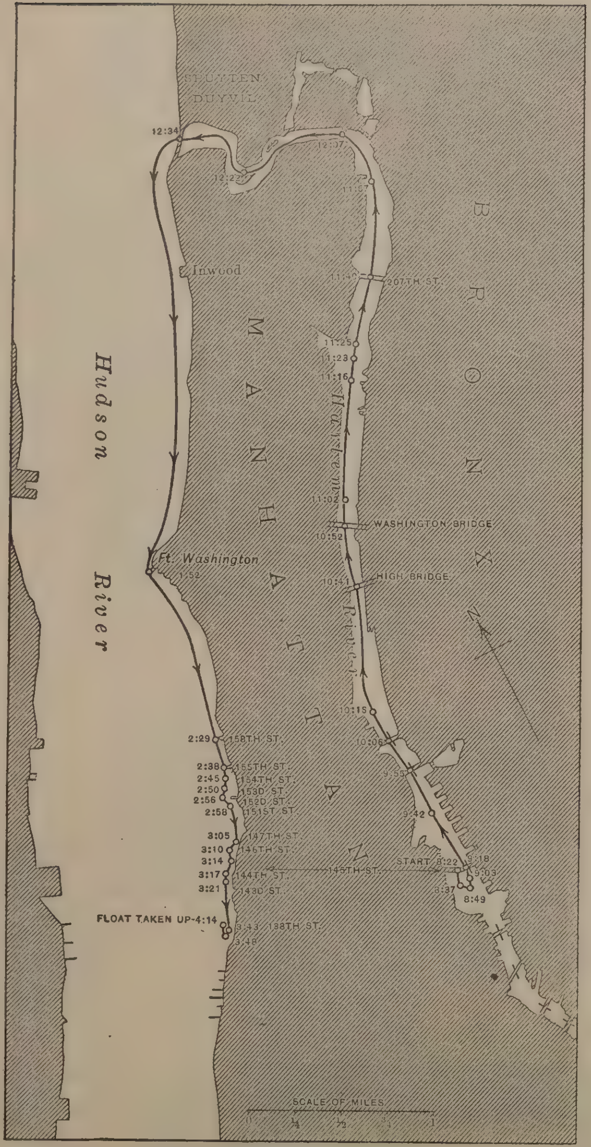


Total distance covered with flood current = 4.05 miles from 10:44 a.m. to 3:35 p.m., 4 hours 51 mins.
Average velocity = 0.89 miles per hour.

FLOAT 8, AUG. 20, 1908

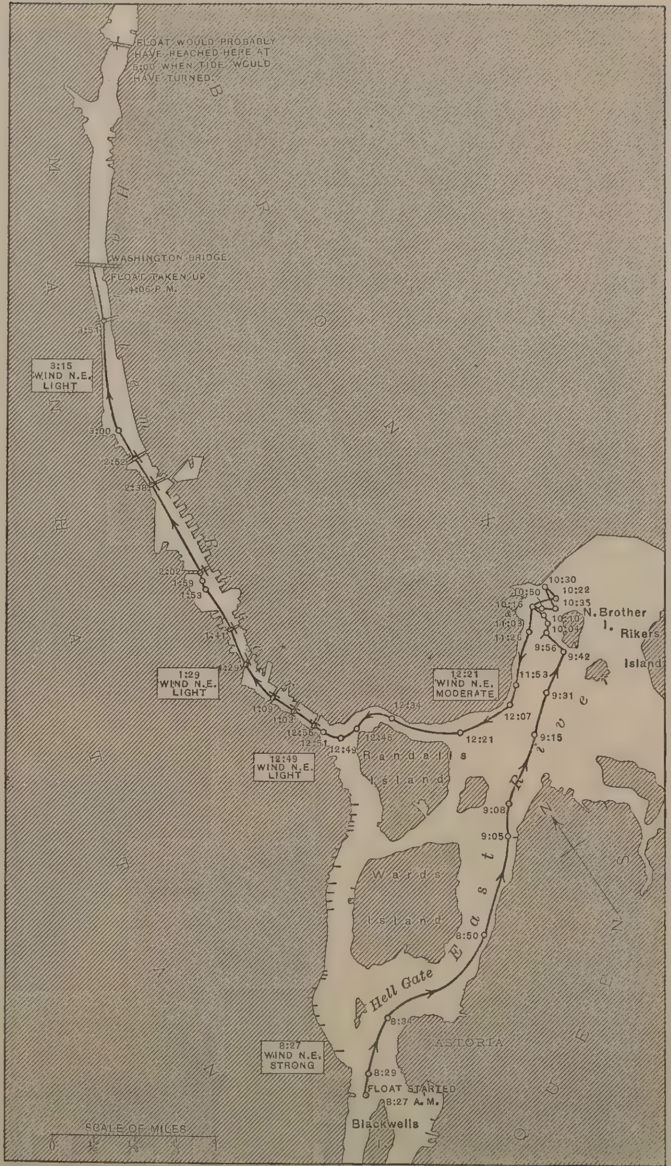
Total distance, ebb, = 1.67 miles in 2.15 hours
Average velocity . . . . = 0.78 miles per hour
Maximum " . . . . = 1.38 " " "
Flood, maximum velocity . . . . = 2.00 " " "

Paths of Floats in the Harlem River



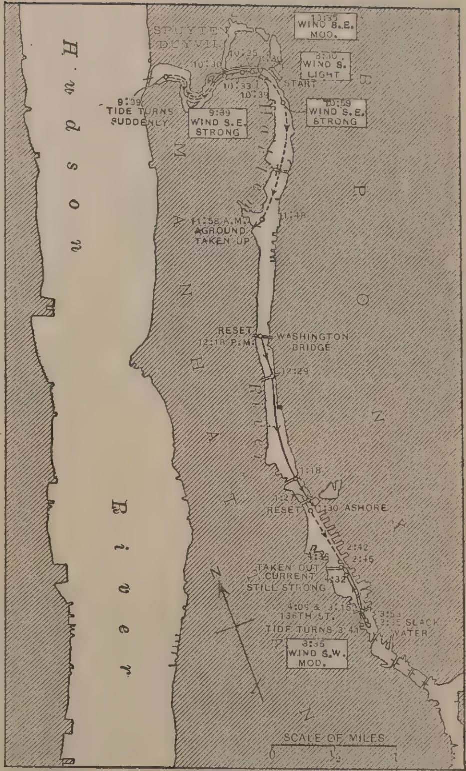
FLOAT 11, AUG. 25, 1908

Total distance, ebb, = 10.25 miles in 6.98 hours
Average velocity .... = 1.47 miles per hour
Maximum " .... = 2.79 " " "



FLOAT 14, AUG. 28, 1908

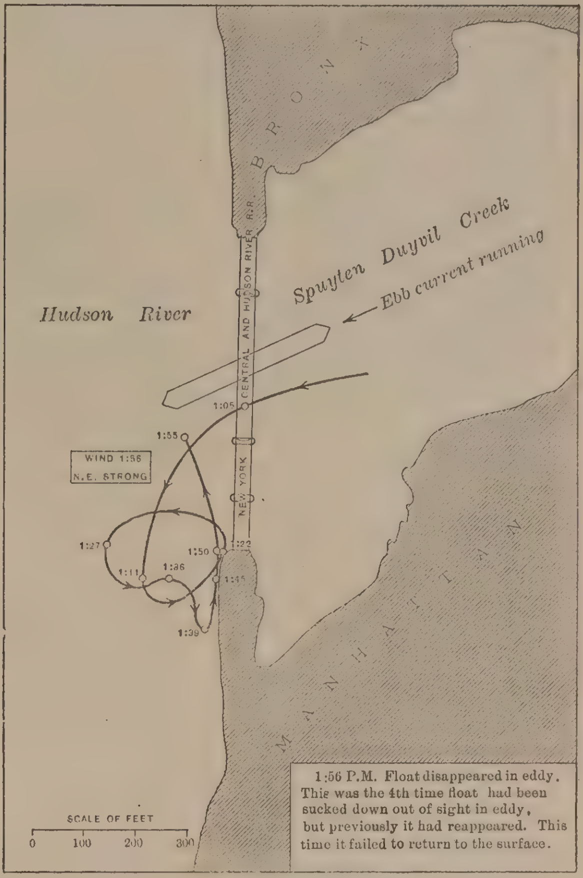
Total distance, flood, = 3.62 miles in 2.05 hours
Average velocity .... = 1.77 miles per hour
Maximum " .... = 4.20 " " "
Total distance, ebb, = 5.42 miles in 5.60 hours
Average velocity .... = 0.97 miles per hour
Maximum " .... = 1.49 " " "



FLOAT 7, AUG. 19, 1908

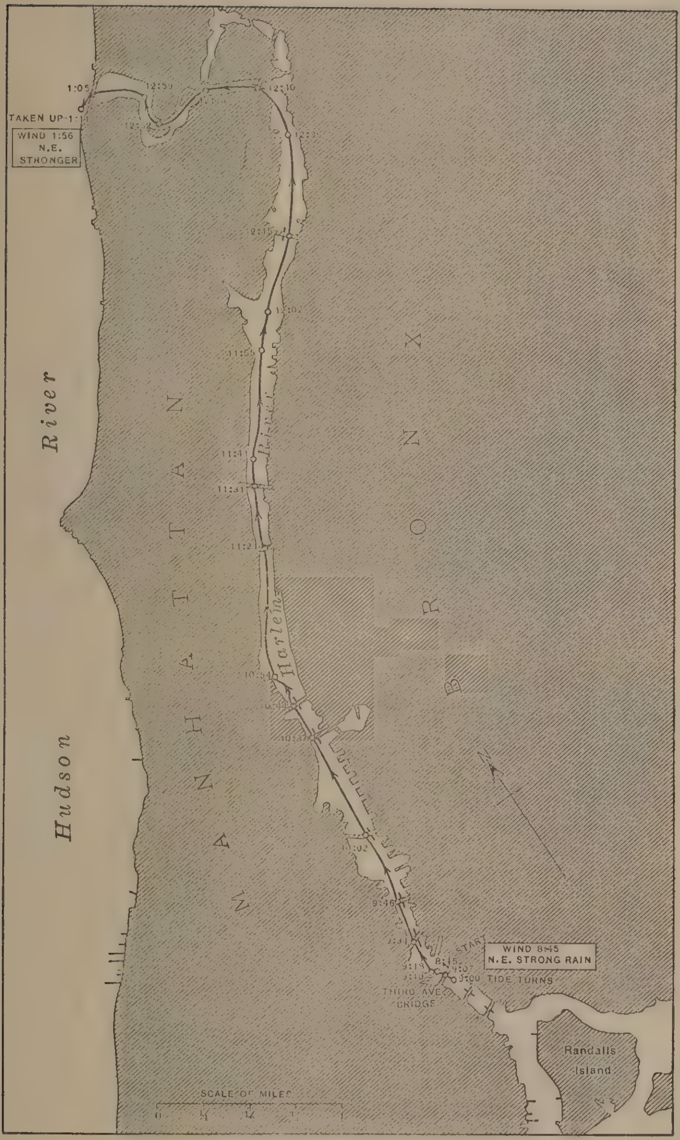
Total distance, flood, = 4.58 miles in 5.72 hours
Average velocity .... = 0.80 miles per hour
Maximum " .... = 1.22 " " "

Paths of Floats in the Harlem River



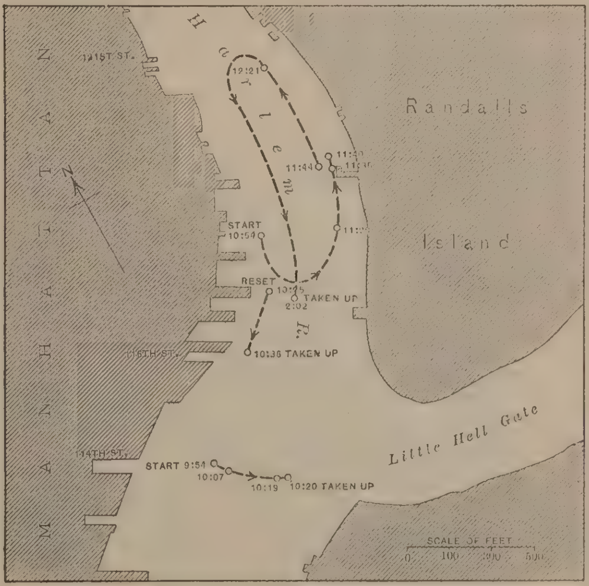
1:56 P.M. Float disappeared in eddy. This was the 4th time float had been sucked down out of sight in eddy, but previously it had reappeared. This time it failed to return to the surface.

FLOAT 12A, AUG. 26, 1908



FLOAT 12, AUG. 26, 1908

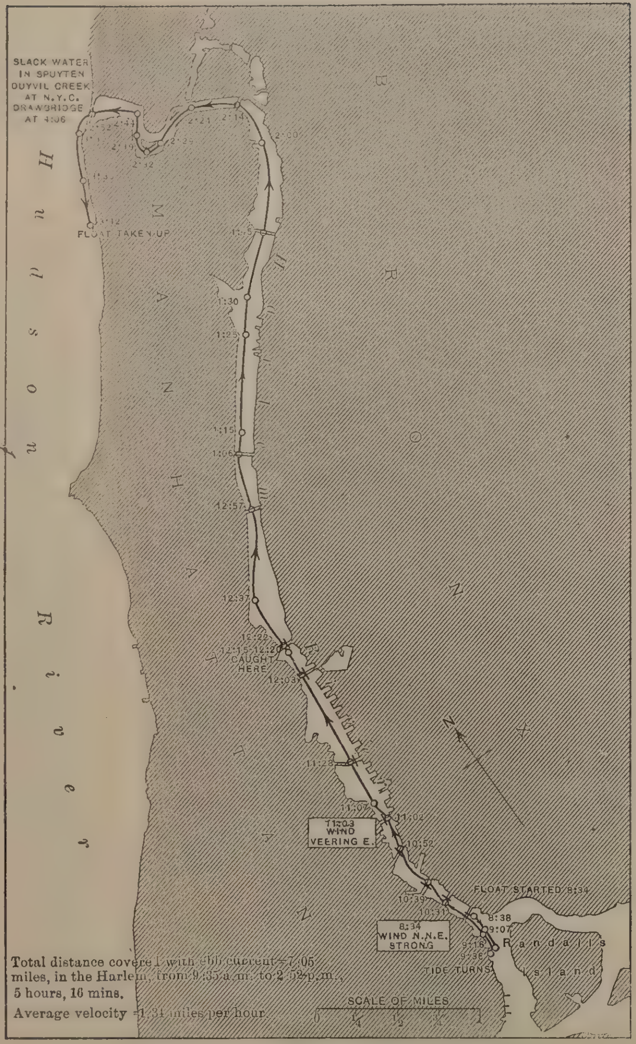
Total distance, ebb, = **6.45** miles in **4.18** hours
Average velocity.... = **1.54** miles per hour
Maximum " .... = **2.52** " " "



FLOAT 2, AUG. 15, 1908

Total distance, flood, = **0.4** miles in **2.3** hours
Average velocity.... = **0.17** miles per hour
Maximum " .... = **0.32** " " "
Total distance, ebb, = **0.31** miles in **1.45** hours
Average velocity.... = **0.21** miles per hour
Maximum " .... = **0.41** " " "

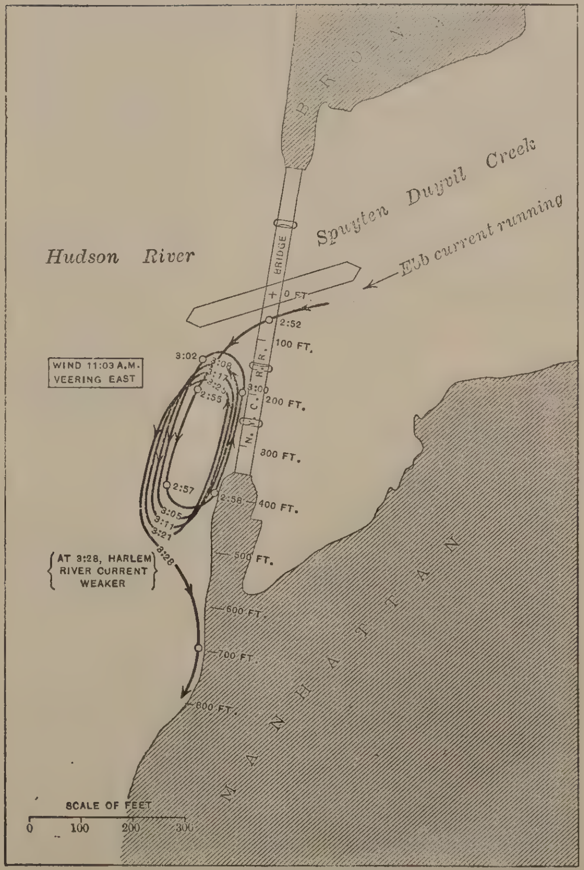
Paths of Floats in the Harlem River



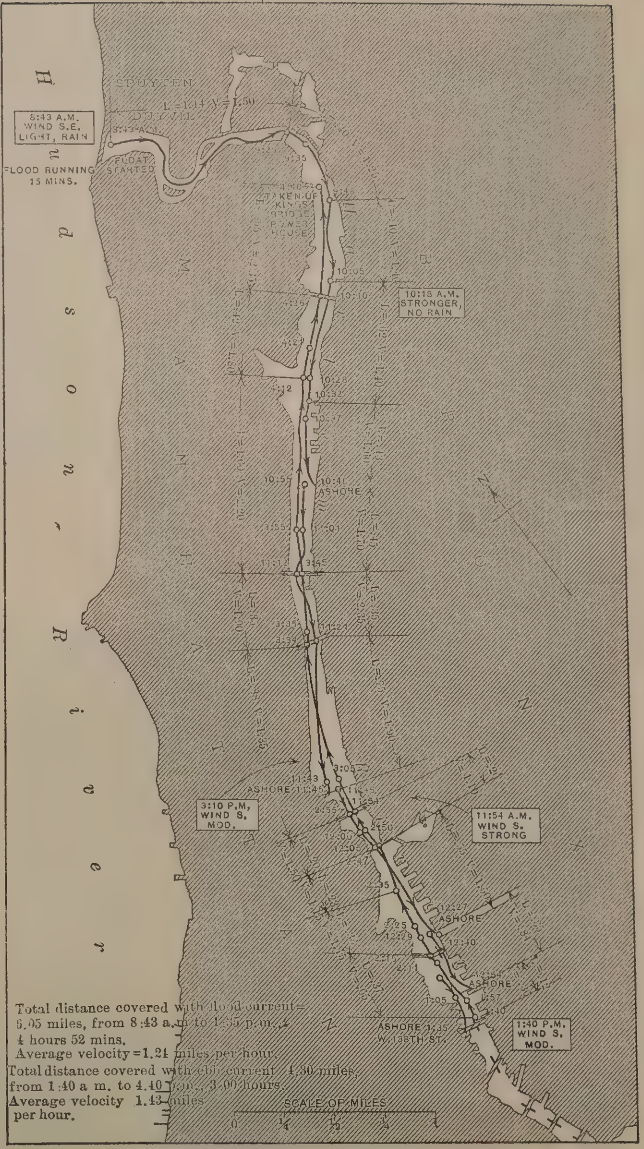
Total distance covered with ebb current=7.05 miles, in the Harlem, from 9:35 a.m. to 2:52 p.m., 5 hours, 16 mins.
Average velocity =1.34 miles per hour.

FLOAT 13, AUG. 27, 1908

Maximum velocity =2.64 miles per hour



FLOAT 13A, AUG. 27, 1908

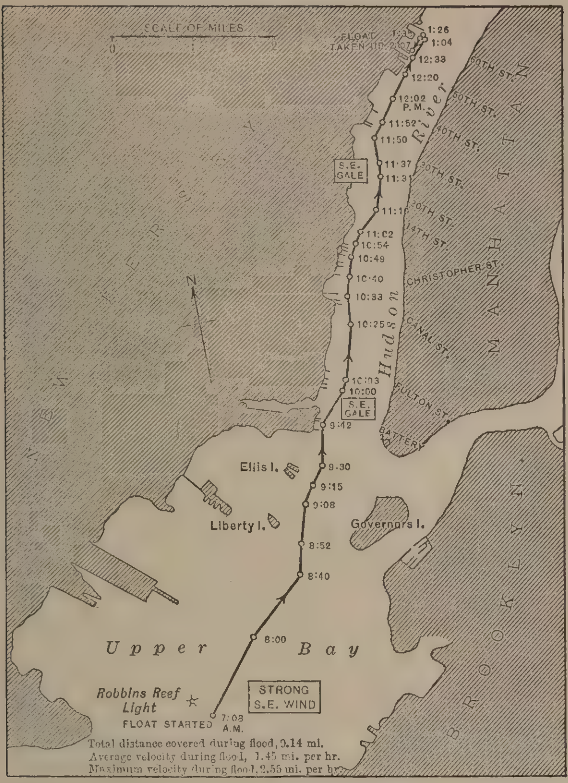


Total distance covered with flood current=6.05 miles, from 8:43 a.m. to 1:35 p.m., 4 hours 52 mins.
Average velocity =1.24 miles per hour.
Total distance covered with ebb current 4.30 miles, from 1:40 a. m. to 4.40 p.m., 3.00 hours.
Average velocity 1.43 miles per hour.

FLOAT 5, AUG. 17, 1908

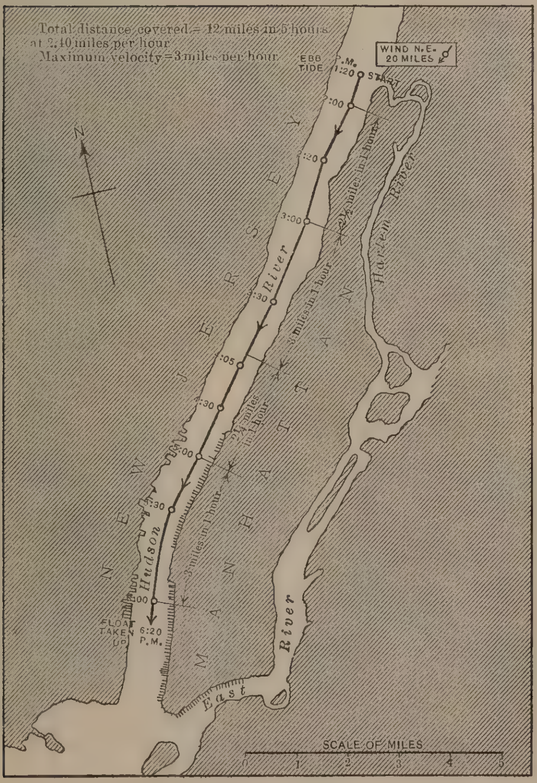
Maximum velocity, flood, =2.35 miles per hour
" " ebb, =2.35 " " "

Paths of Floats in the Harlem River



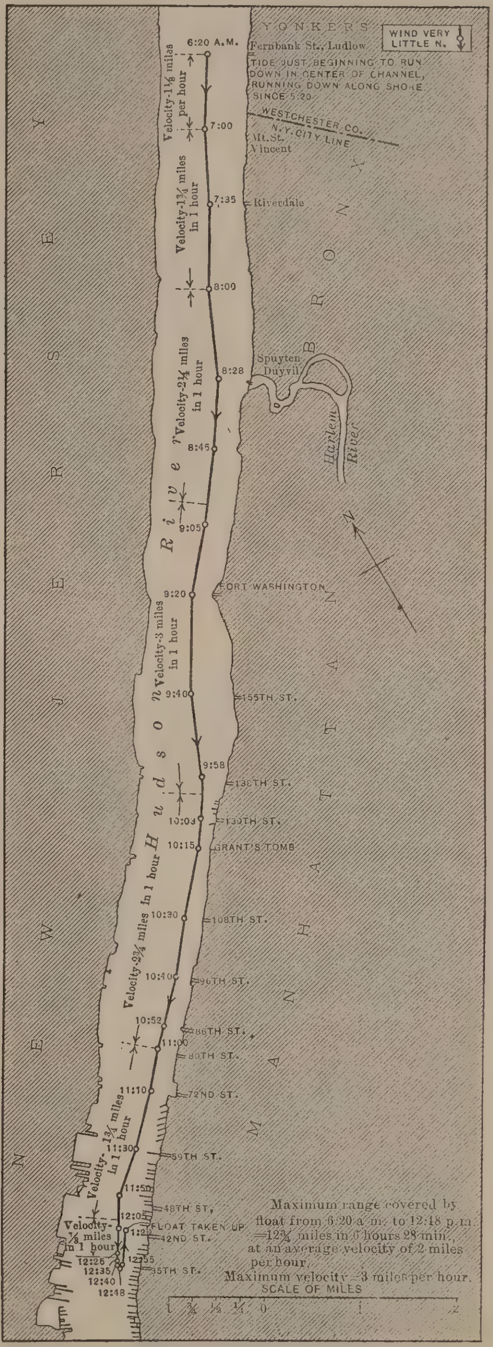
Total distance covered during flood, 9.14 mi.
Average velocity during flood, 1.45 mi. per hr.
Maximum velocity during flood, 2.55 mi. per hr.

FLOAT 34, SEPT. 28, 1908



Total distance covered = 12 miles in 5 hours
at 2.40 miles per hour
Maximum velocity = 3 miles per hour

FLOAT M, APRIL 2, 1907

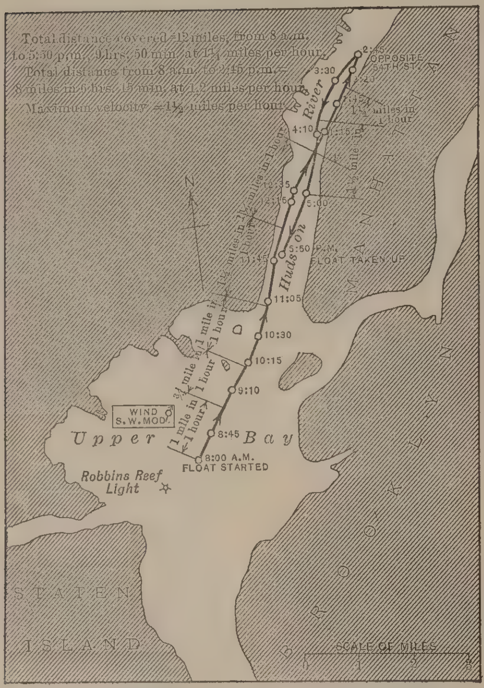


TIDE JUST BEGINNING TO RUN DOWN IN CENTER OF CHANNEL, RUNNING DOWN ALONG SHORE SINCE 5:20

Maximum range covered by float from 6:20 a. m. to 12:48 p. m. = 12¾ miles in 6 hours 28 min., at an average velocity of 2 miles per hour.
Maximum velocity = 3 miles per hour.

FLOAT Y, JULY 19, 1907

Paths of Floats in the Hudson River

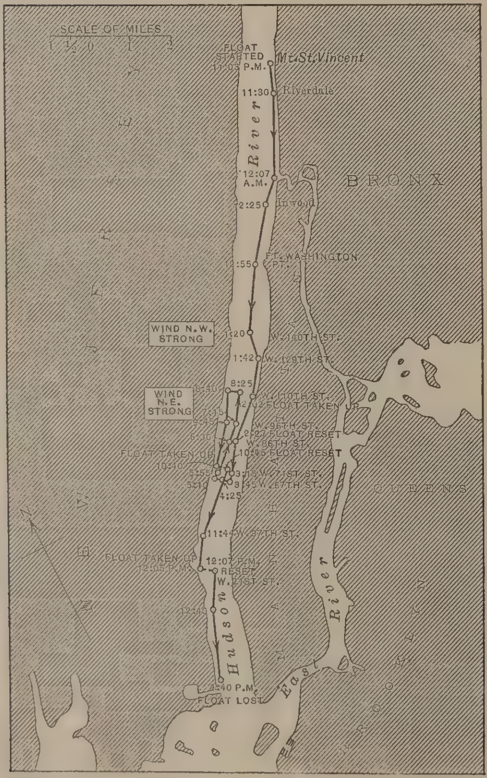


Total distance covered = 12 miles, from 8 a.m. to 5:30 p.m., 9 hrs. 50 min. at $1\frac{1}{4}$ miles per hour.

Total distance from 8 a.m. to 2:45 p.m. = 8 miles in 6 hrs. 15 min. at 1.2 miles per hour.

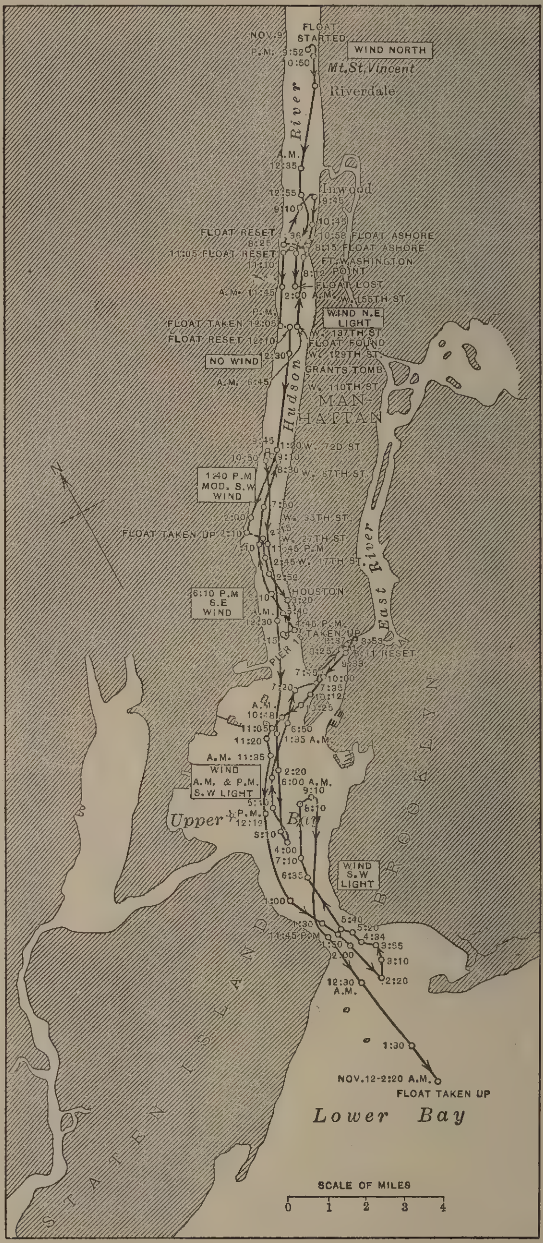
Maximum velocity = $1\frac{1}{2}$ miles per hour.

FLOAT E, MAR. 5, 1907



FLOAT 46, NOV. 8-9, 1909

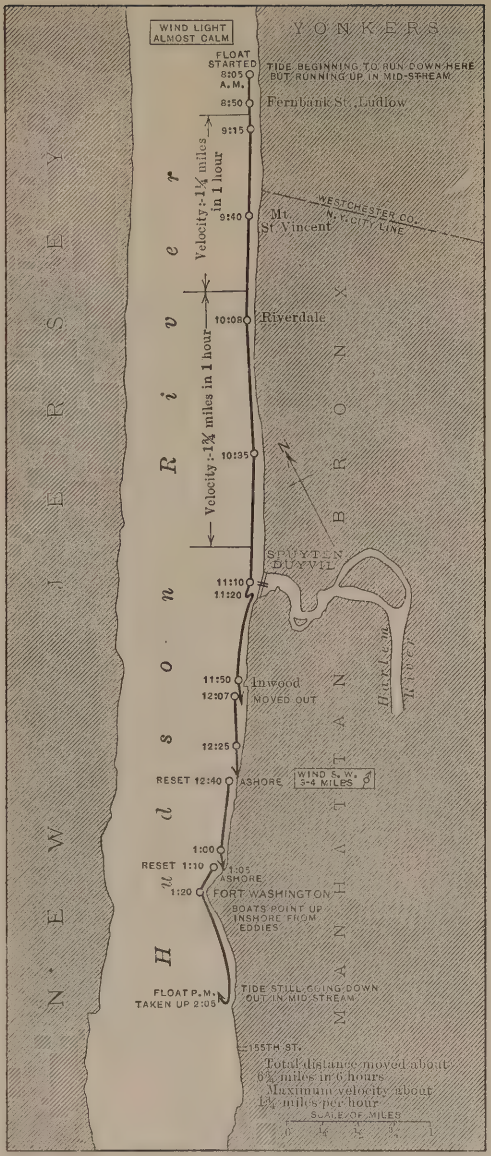
Total distance, ebb, = **16.78** miles in **9.83** hours
Average velocity . . . = **1.71** miles per hour
Maximum " . . . = **4.2** " " "



FLOAT 47, NOV. 9-12, 1909

Total distance, flood,—**20.45** miles in **20.05** hours
Average velocity . . . . = **1.02** miles per hour
Maximum " . . . . = **1.75** " " "
Total distance, ebb, = **47.2** miles in **27.22** hours
Average velocity . . . . = **1.73** miles per hour
Maximum " . . . . = **3.2** " " "

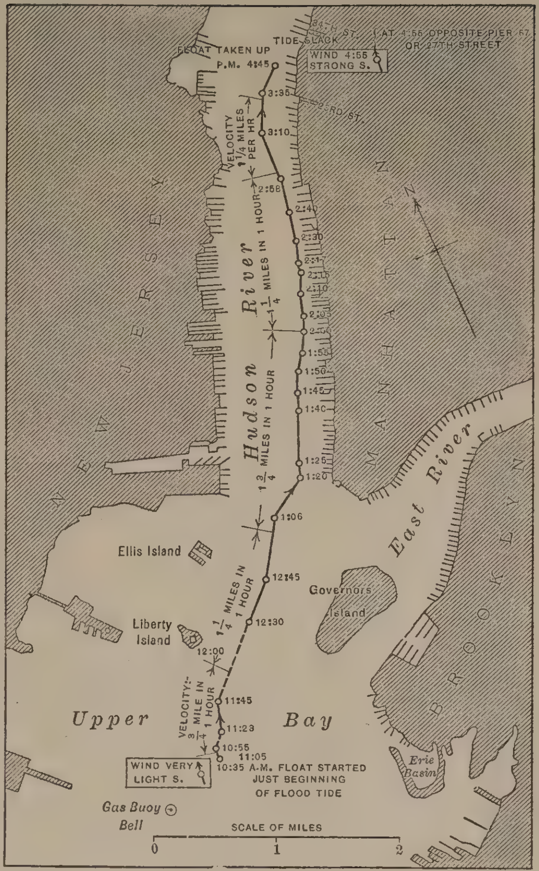
Paths of Floats in the Hudson River



Total distance moved about 6¾ miles in 6 hours
Maximum velocity about 1¾ miles per hour

FLOAT 7, JULY 22, 1907

Average velocity, ebb, =1.13 miles per hour

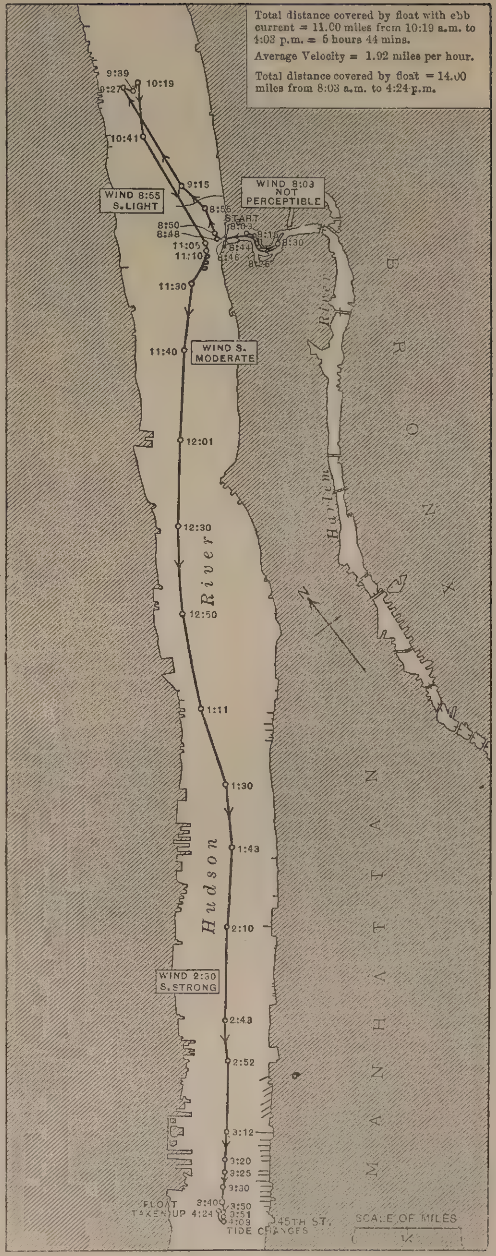


FLOAT X, JULY 17, 1907

Total distance, flood, =6.0 miles in 6.17 hours
Average velocity.... =0.97 miles per hour
Maximum " .... =1.75 " " "

FLOAT 24

Total distance, flood, =3.0 miles in 1.81 hours
Average velocity.... =1.65 miles per hour
Maximum " .... =4.4 " " "
Ebb, maximum velocity........... =3.84 " " "



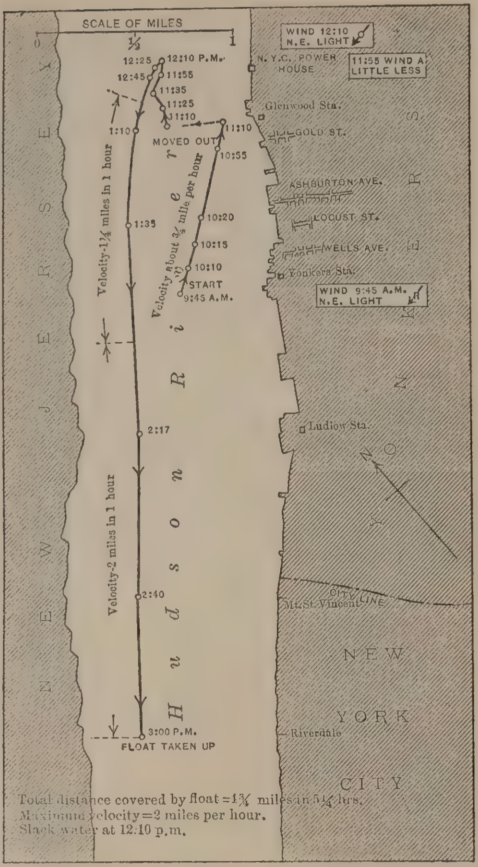
Total distance covered by float with ebb current = 11.00 miles from 10:19 a.m. to 4:03 p.m. = 5 hours 44 mins.

Average Velocity = 1.92 miles per hour.

Total distance covered by float = 14.00 miles from 8:03 a.m. to 4:24 p.m.

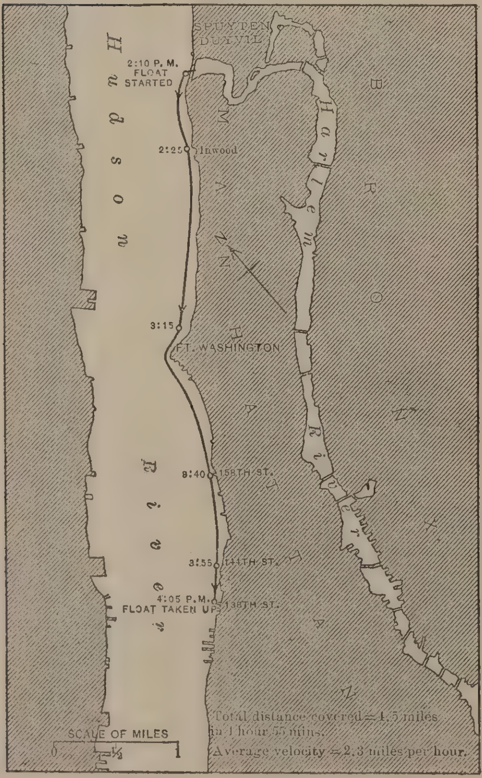
FLOAT 24, SEPT. 9, 1908

Paths of Floats in the Hudson River



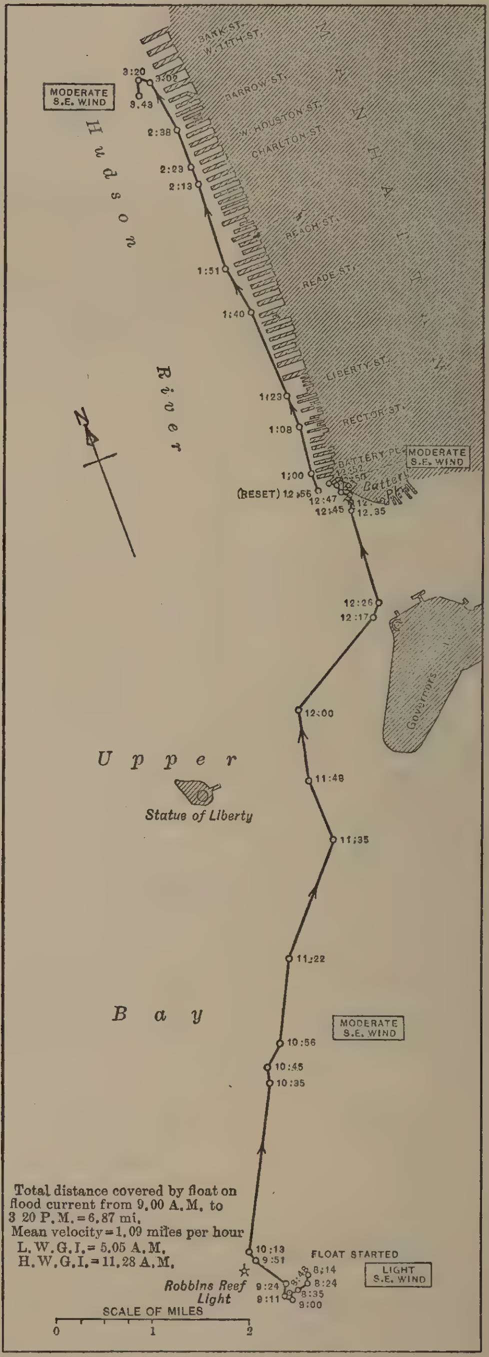
Total distance covered by float = 4¾ miles in 5¼ hrs.
Maximum velocity = 2 miles per hour.
Slack water at 12:10 p.m.

FLOAT V, JULY 11, 1907
Average velocity, ebb, = 0.9 miles per hour



Total distance covered = 4.5 miles in 1 hour 55 mins.
Average velocity = 2.3 miles per hour.

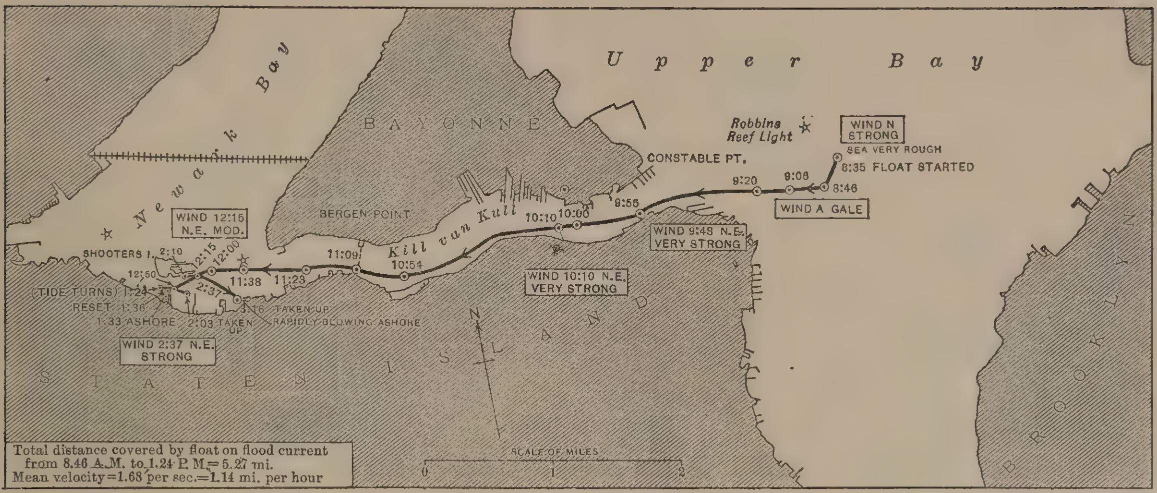
FLOAT 1, AUG. 14, 1908
Maximum velocity, ebb, = 3.07 miles per hour



Total distance covered by float on flood current from 9.00 A.M. to 3 20 P.M. = 6.87 mi.
Mean velocity = 1.09 miles per hour
L.W.G.I. = 5.05 A.M.
H.W.G.I. = 11.28 A.M.

FLOAT 37, OCT. 1, 1908
Maximum velocity, flood,—3.0 miles per hour

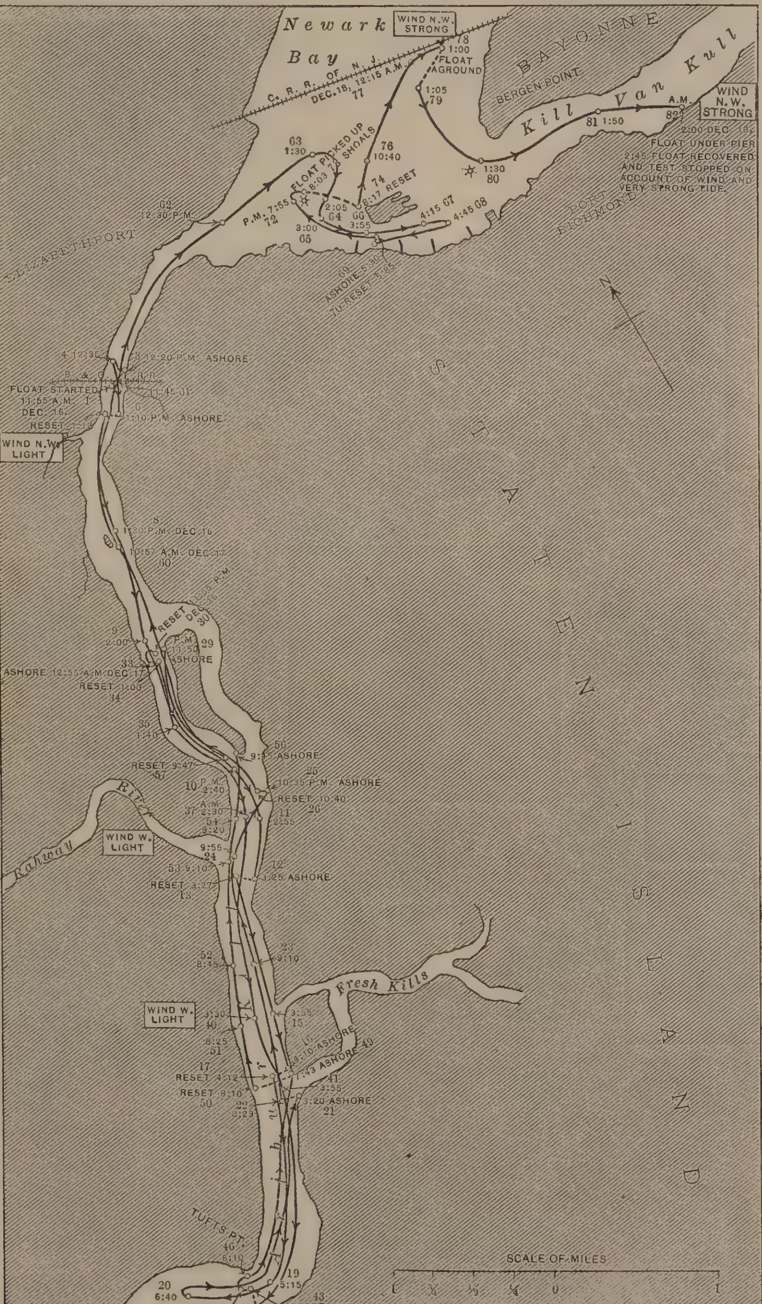
Paths of Floats in the Hudson River and Upper Bay



Total distance covered by float on flood current from 8.46 A.M. to 1.24 P.M. = 5.27 mi.
Mean velocity = 1.68′ per sec. = 1.14 mi. per hour

FLOAT 28, SEPT. 16, 1908

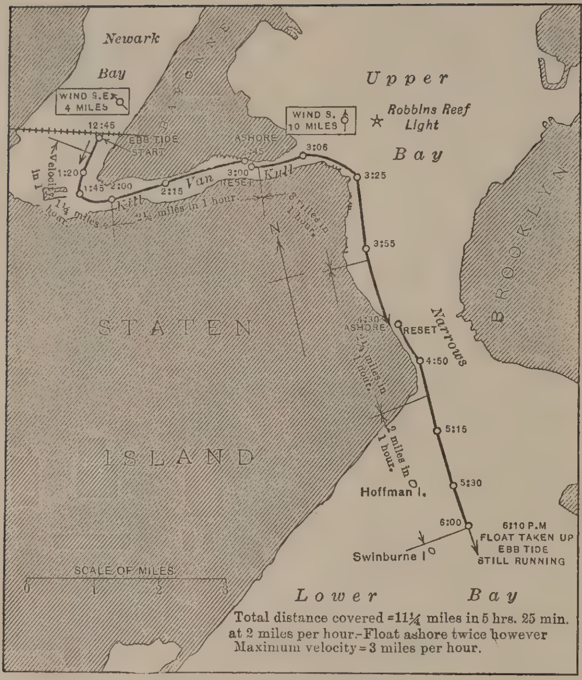
Maximum velocity, flood, = 2.6 miles per hour



FLOAT 61, DEC. 16-18, 1909

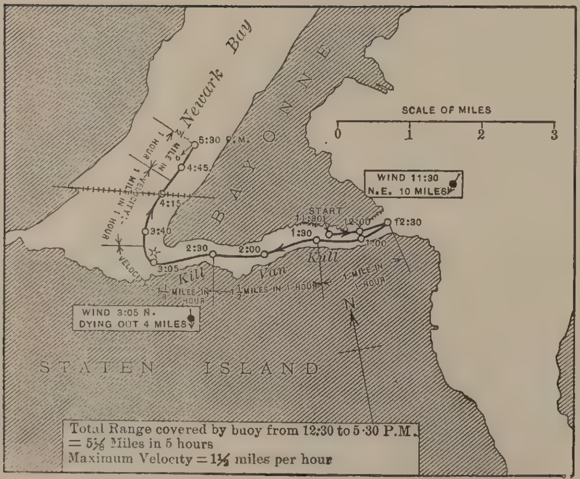
Total distance, flood, = 16.97 miles in 21.5 hours
Average velocity.... = 0.79 miles per hour
Maximum " .... = 1.80 " "
Total distance, ebb, = 11.8 miles in 15.0 hours
Average velocity.... = 0.79 miles per hour
Maximum " .... = 2.33 " "

Paths of Floats in the Kill Van Kull and Arthur Kill



Total distance covered = 11¼ miles in 5 hrs. 25 min. at 2 miles per hour.-Float ashore twice however
Maximum velocity = 3 miles per hour.

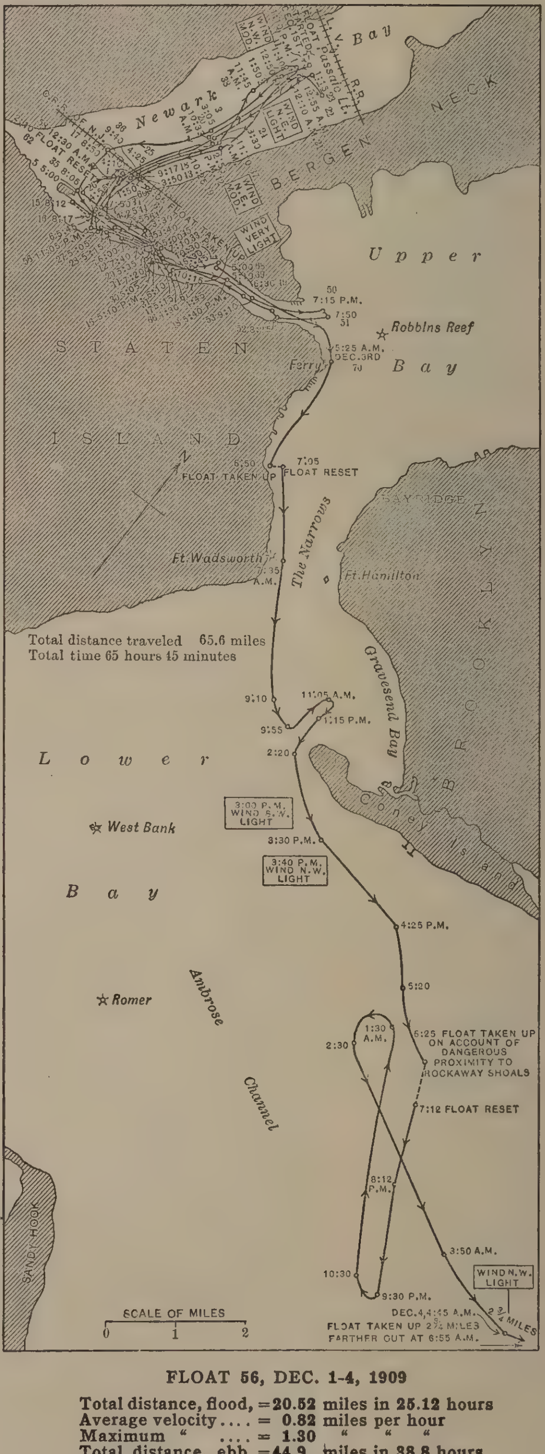
FLOAT 19, SEPT. 3, 1908



Total Range covered by buoy from 12:30 to 5·30 P.M.
= 5⅛ Miles in 5 hours
Maximum Velocity = 1½ miles per hour

FLOAT Q, APRIL 8, 1907

Average velocity, flood, = 1.02 miles per hour

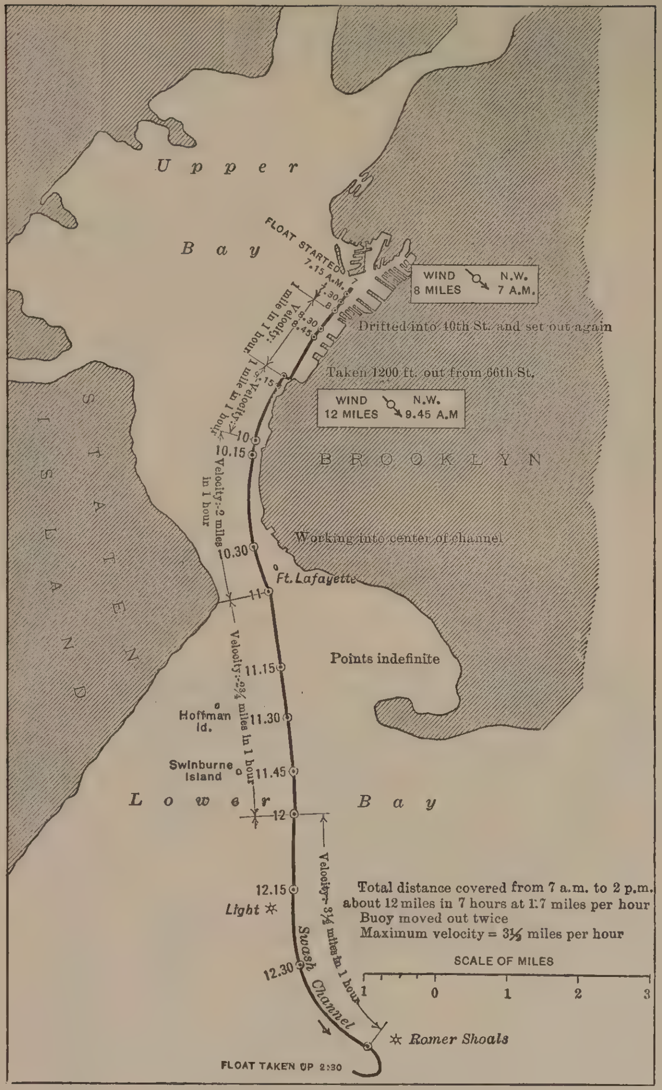


Total distance traveled 65.6 miles
Total time 65 hours 45 minutes

FLOAT 56, DEC. 1-4, 1909

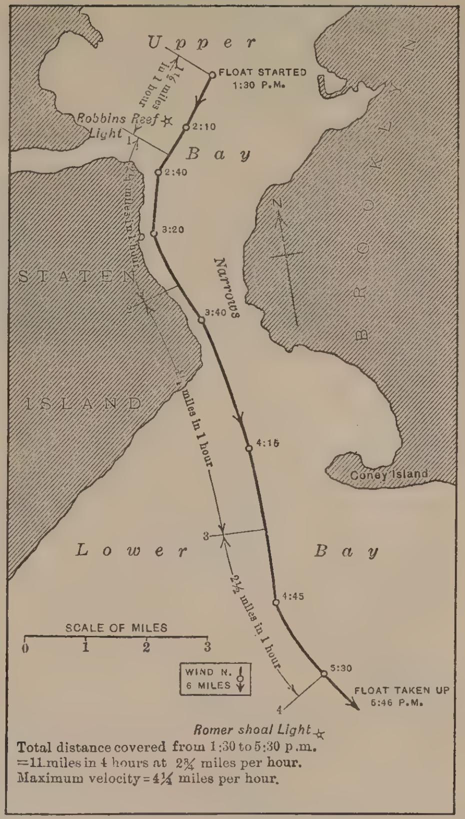
Total distance, flood, = 20.52 miles in 25.12 hours
Average velocity .... = 0.82 miles per hour
Maximum " .... = 1.30 " " "
Total distance, ebb, = 44.9 miles in 38.8 hours
Average velocity .... = 1.16 miles per hour
Maximum " .... = 4.05 " " "

Paths of Floats in Newark Bay and Kill Van Kull


Upper Bay
FLOAT STARTED 7.15 A.M.
WIND 8 MILES N.W. 7 A.M.
Drifted into 40th St. and set out again
Velocity: 1 mile in 1 hour
Taken 1200 ft. out from 66th St.
WIND 12 MILES N.W. 9.45 A.M
Velocity: 1 mile in 1 hour
10.15
BROOKLYN
STATEN ISLAND
Velocity:-2 miles in 1 hour
Working into center of channel
10.30
Ft. Lafayette
11
Points indefinite
Velocity:-2¾ miles in 1 hour
11.15
Hoffman Id.
11.30
Swinburne Island
11.45
Lower Bay
12
Velocity- 3⅛ miles in 1 hour
12.15
Light
12.30
Swash Channel
Romer Shoals
FLOAT TAKEN UP 2:30
SCALE OF MILES
1 0 1 2 3

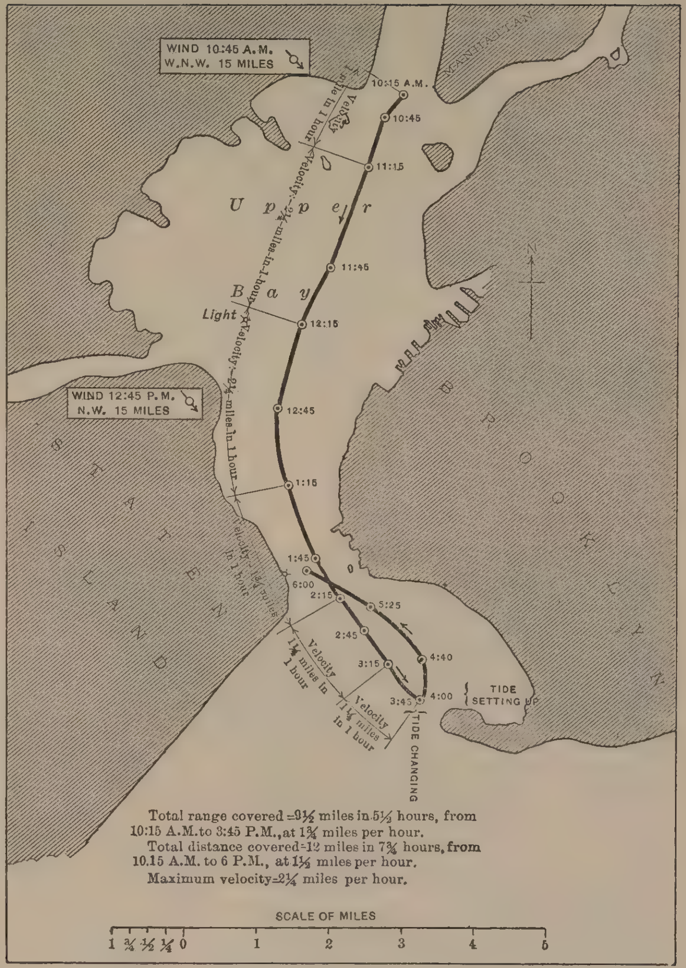
Total distance covered from 7 a.m. to 2 p.m. about 12 miles in 7 hours at 1.7 miles per hour
Buoy moved out twice
Maximum velocity = $3\frac{1}{5}$ miles per hour

FLOAT A, FEB. 23, 1907



Total distance covered from 1:30 to 5:30 p.m. =11 miles in 4 hours at $2\frac{3}{4}$ miles per hour.
Maximum velocity = $4\frac{1}{4}$ miles per hour.

FLOAT D, MAR. 4, 1907


WIND 10:45 A.M. W.N.W. 15 MILES
MANHATTAN
10:15 A.M.
10:45
Velocity 1 mile in 1 hour
11:15
Upper Bay
Velocity:-2¼ miles in 1 hour
11:45
Light
12:15
WIND 12:45 P.M. N.W. 15 MILES
Velocity:-2¼ miles in 1 hour
12:45
1:15
STATEN ISLAND
BROOKLYN
Velocity:-1¾ miles in 1 hour
1:45
6:00
2:15
5:25
2:45
Velocity 1¼ miles in 1 hour
3:15
Velocity 1⅛ miles in 1 hour
4:40
4:00
3:45
TIDE SETTING UP
TIDE CHANGING
SCALE OF MILES
1 ¾ ½ ¼ 0 1 2 3 4 5

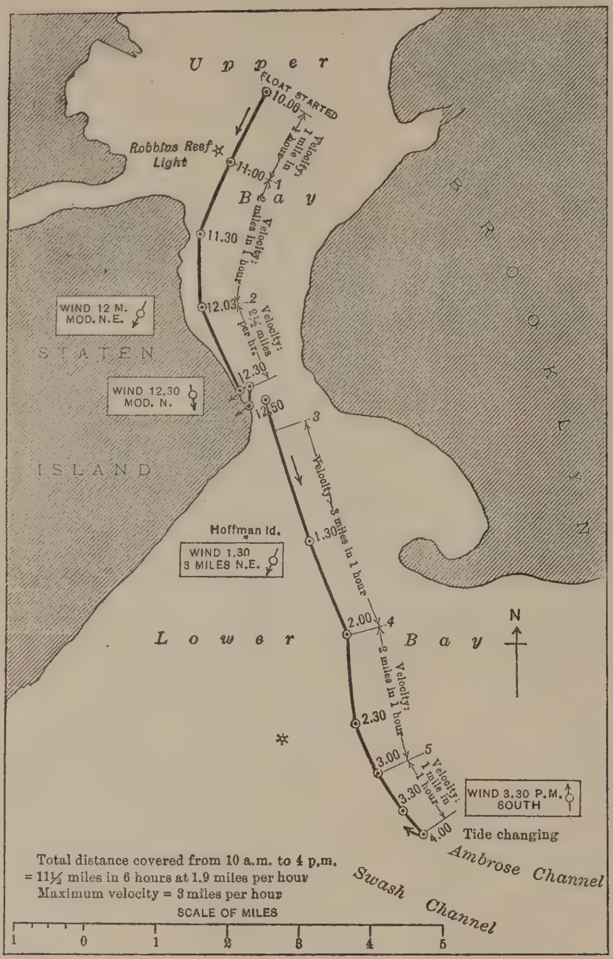
Total range covered = $9\frac{1}{2}$ miles in $5\frac{1}{2}$ hours, from 10:15 A.M. to 3:45 P.M., at $1\frac{3}{4}$ miles per hour.

Total distance covered = 12 miles in $7\frac{3}{4}$ hours, from 10.15 A.M. to 6 P.M., at $1\frac{1}{2}$ miles per hour.

Maximum velocity = $2\frac{1}{4}$ miles per hour.

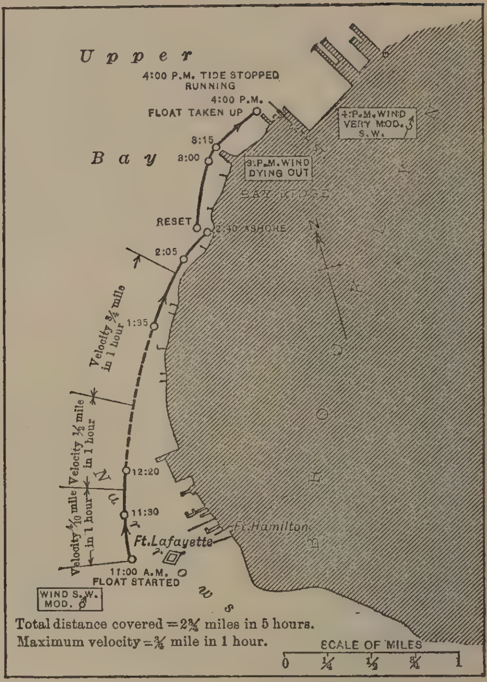
FLOAT B, FEB. 25, 1907

Paths of Floats in the Upper Bay



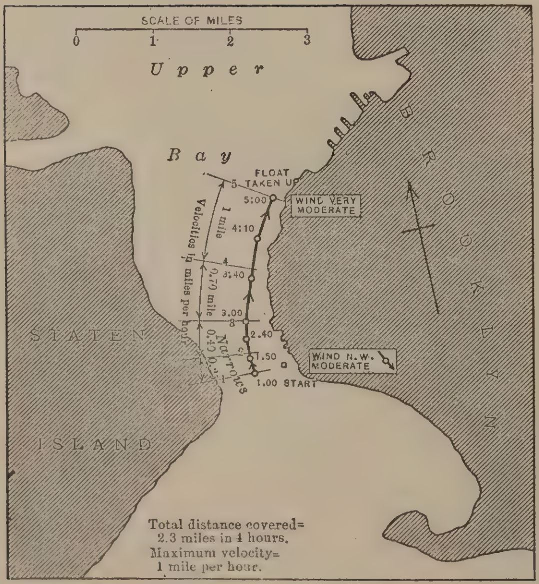
Total distance covered from 10 a.m. to 4 p.m.
= 11½ miles in 6 hours at 1.9 miles per hour
Maximum velocity = 3 miles per hour

FLOAT C, FEB. 26 1907



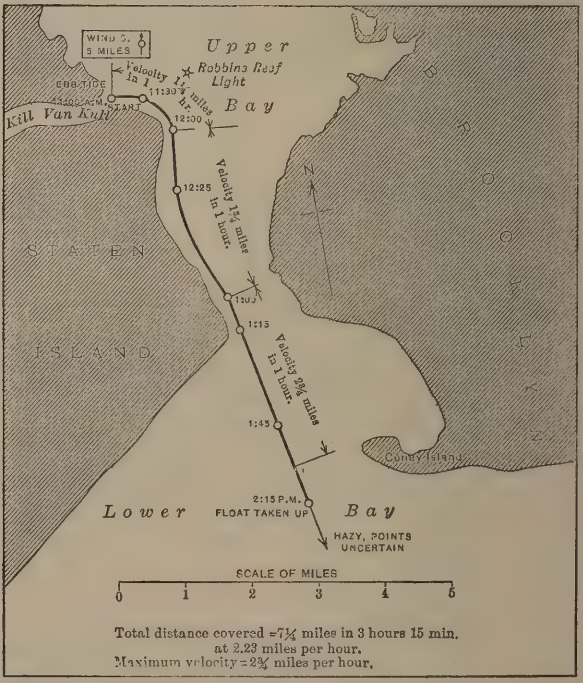
Total distance covered = 2¾ miles in 5 hours.
Maximum velocity = ¾ mile in 1 hour.

FLOAT G, MAR. 22, 1907
Average velocity, flood, = 0.55 miles per hour



Total distance covered=
2.3 miles in 4 hours.
Maximum velocity=
1 mile per hour.

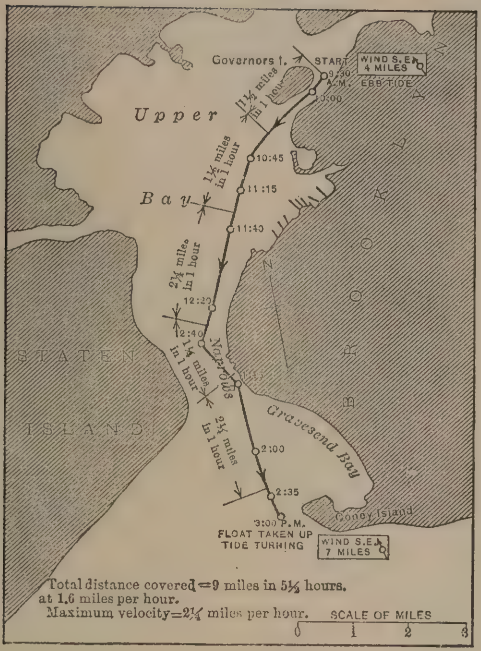
FLOAT H, MAR. 23, 1907
Average velocity, flood, = 0.58 miles per hour



Total distance covered = 7¼ miles in 3 hours 15 min.
at 2.23 miles per hour.
Maximum velocity = 2¾ miles per hour.

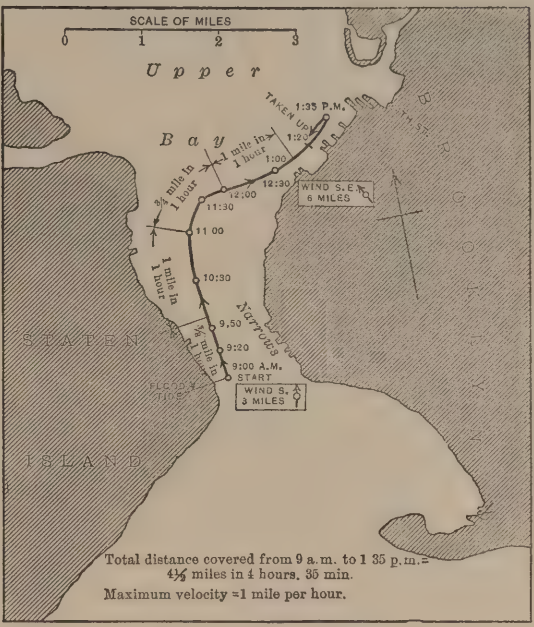
FLOAT K, MAR. 28, 1907

Paths of Floats in the Upper Bay



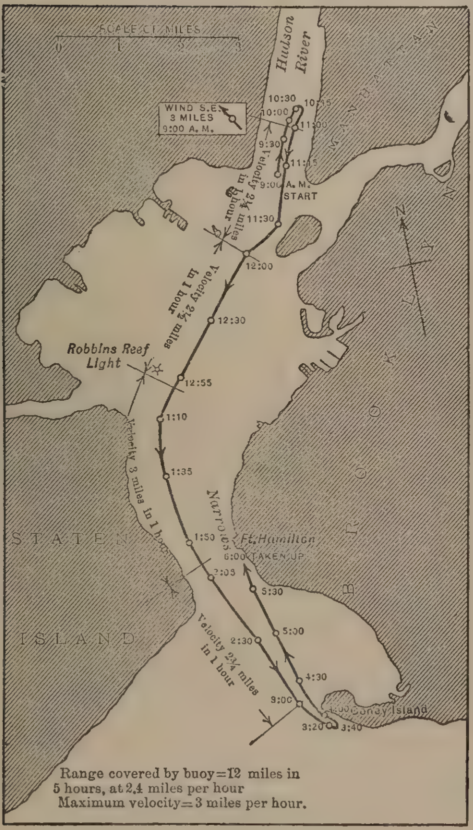
Total distance covered = 9 miles in 5½ hours, at 1.6 miles per hour.
Maximum velocity = 2¼ miles per hour.

FLOAT J, MAR. 27, 1907



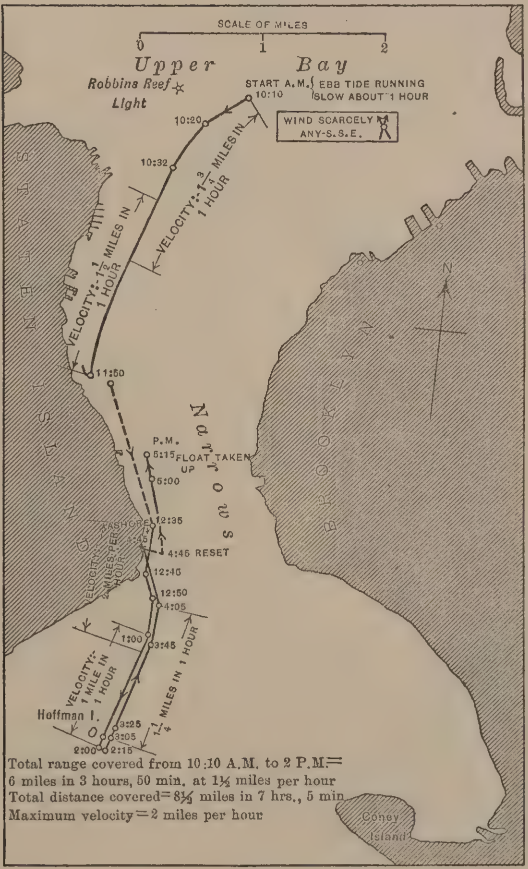
Total distance covered from 9 a.m. to 1 35 p.m. = 4⅗ miles in 4 hours, 35 min.
Maximum velocity = 1 mile per hour.

FLOAT O, APRIL 4, 1907
Average velocity, flood, = 0.98 miles per hour



Range covered by buoy = 12 miles in 5 hours, at 2.4 miles per hour
Maximum velocity = 3 miles per hour.

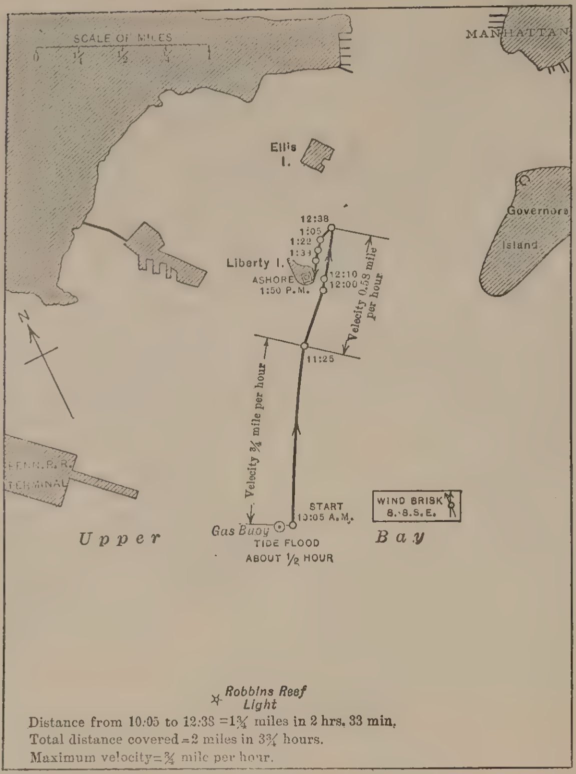
FLOAT R, APRIL 12, 1907



Total range covered from 10:10 A.M. to 2 P.M. = 6 miles in 3 hours, 50 min. at 1½ miles per hour
Total distance covered = 8½ miles in 7 hrs., 5 min
Maximum velocity = 2 miles per hour

FLOAT T, JULY 8, 1907
Total distance, flood, = 2.5 miles in 3.25 hours
Average velocity.... = 0.77 miles per hour
Maximum " .... = 1.25 " " "

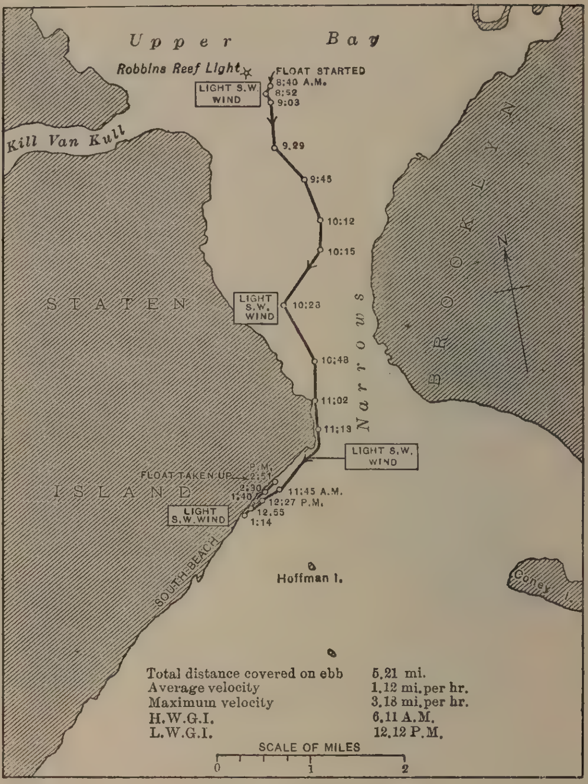
Paths of Floats in the Upper Bay



Distance from 10:05 to 12:38 = 1¾ miles in 2 hrs. 33 min.
Total distance covered = 2 miles in 3¾ hours.
Maximum velocity = ¾ mile per hour.

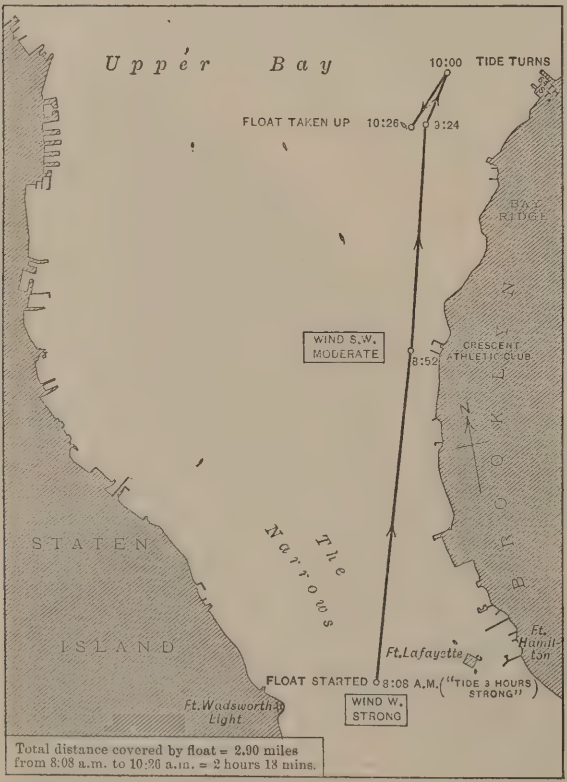
FLOAT W, JULY 16, 1907

Average velocity, flood, = 0.69 miles per hour



Total distance covered on ebb 5.21 mi.
Average velocity 1.12 mi. per hr.
Maximum velocity 3.18 mi. per hr.
H.W.G.I. 6.11 A.M.
L.W.G.I. 12.12 P.M.

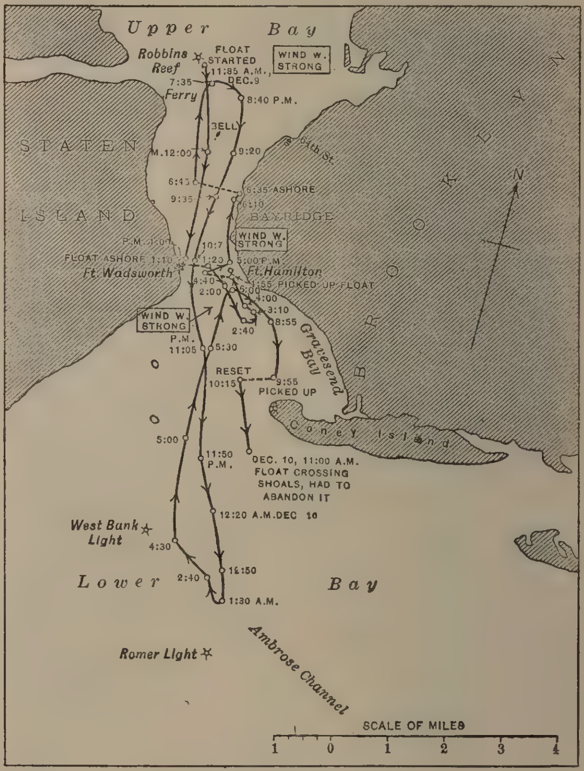
FLOAT 31, SEPT. 22, 1908



Total distance covered by float = 2.90 miles from 8:08 a.m. to 10:26 a.m. = 2 hours 18 mins.

FLOAT 26, SEPT. 11, 1908

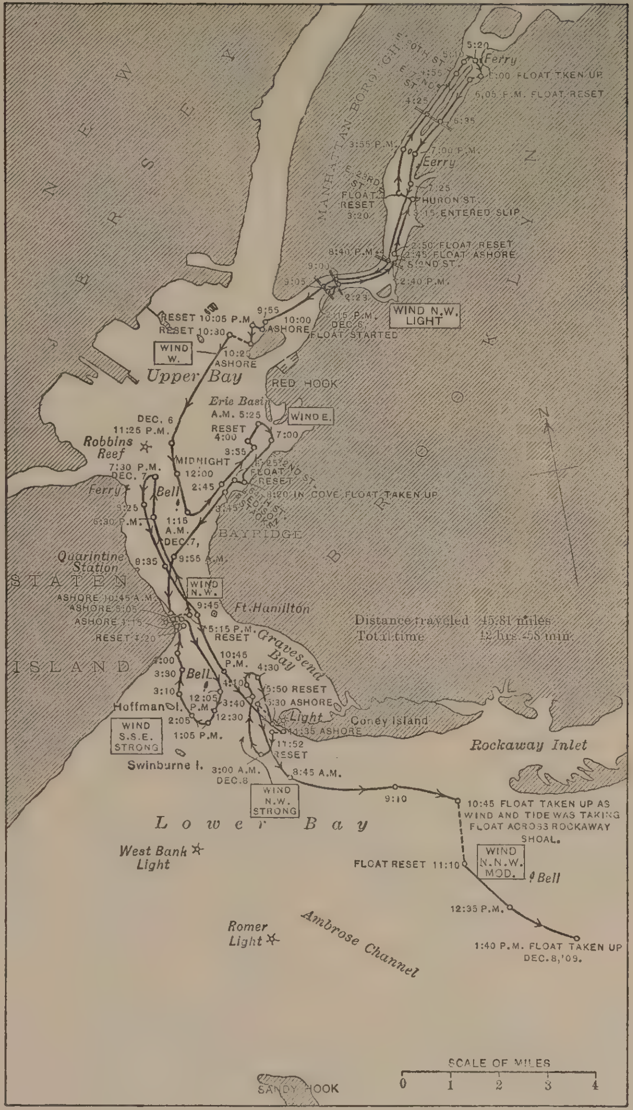
Average velocity, flood, = 1.26 miles per hour
Maximum " " = 1.94 " " "



FLOAT 58, DEC. 9-10, 1909

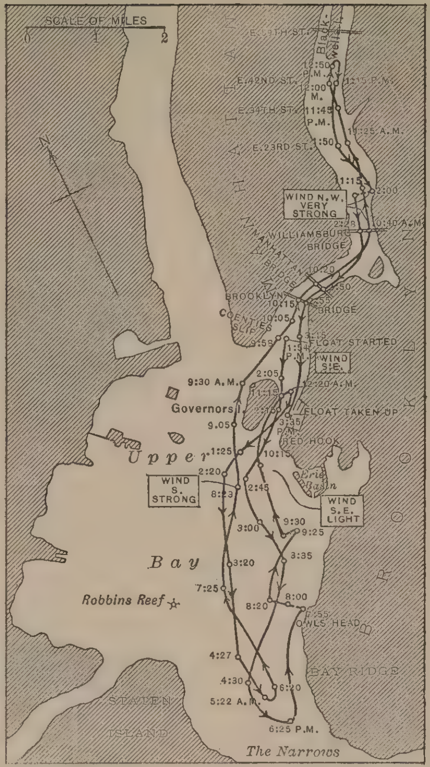
Total distance, flood, = 10.6 miles in 9.17 hours
Average velocity.... = 1.16 miles per hour
Maximum " .... = 3.64 " " "
Total distance, ebb, = 17.18 miles in 13.5 hours
Average velocity.... = 1.27 miles per hour
Maximum " .... = 3.4 " " "

Paths of Floats in the Upper Bay



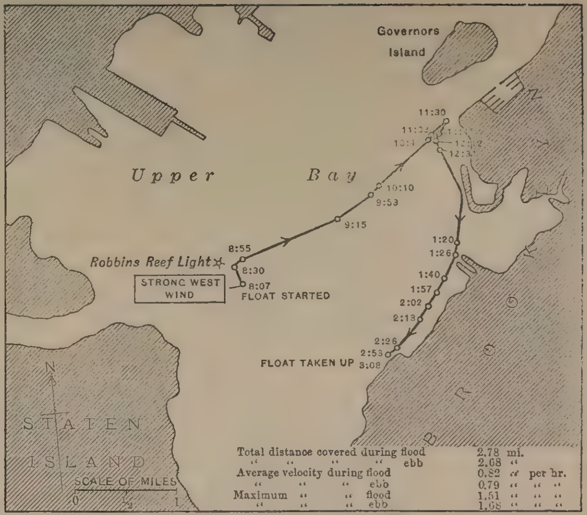
FLOAT 57, DEC. 6-8, 1909

Total distance, flood, = **15.8** miles in **14.75** hours
Average velocity .... = **1.07** miles per hour
Maximum " .... = **4.64** " " "
Total distance, ebb, = **34.44** miles in **30.8** hours
Average velocity .... = **1.12** miles per hour
Maximum " .... = **3.81** " " "



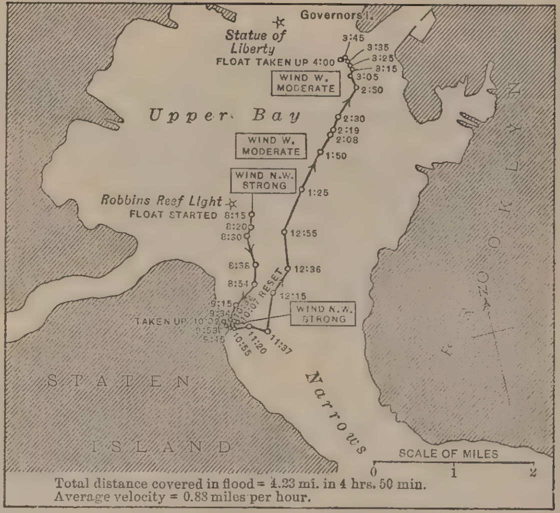
FLOAT 49, NOV. 16-17, 1909

Total distance, flood, = **15.7** miles in **13.22** hours
Average velocity .... = **1.19** miles per hour
Maximum " .... = **4.82** " " "
Total distance, ebb, = **17.1** miles in **12.3** hours
Average velocity .... = **1.39** miles per hour
Maximum " .... = **4.88** " " "



Total distance covered during flood	2.78	mi.
" " " " ebb	2.68	"
Average velocity during flood	0.82	" per hr.
" " " ebb	0.79	" " "
Maximum " " flood	1.51	" " "
" " " ebb	1.68	" " "

FLOAT 35, SEPT. 29, 1908

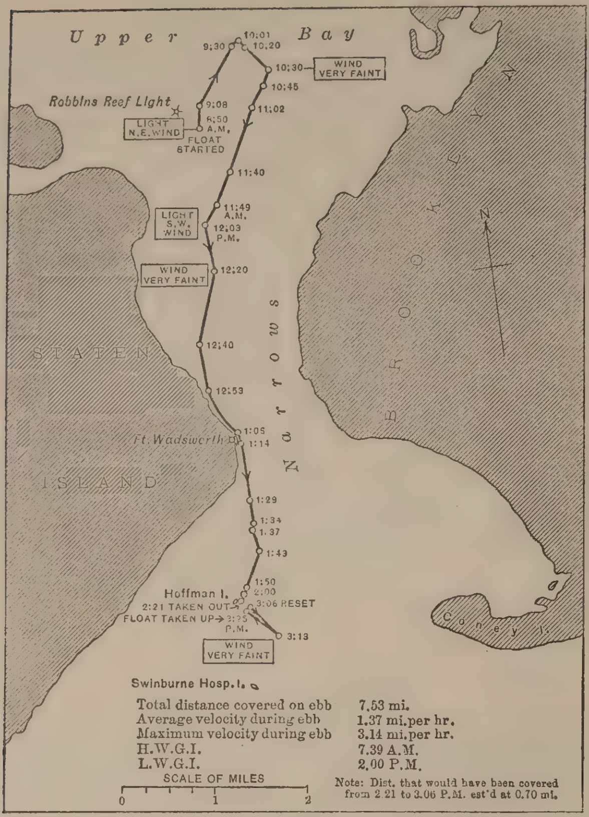


Total distance covered in flood = 4.23 mi. in 4 hrs. 50 min.
Average velocity = 0.88 miles per hour.

FLOAT 29, SEPT. 17, 1908

Total distance, ebb..... = **1.82** miles in **1.78** hours
Average velocity .... = **1.02** miles per hour
Maximum " .... = **3.0** " " "
Flood maximum velocity = **1.58** " " "

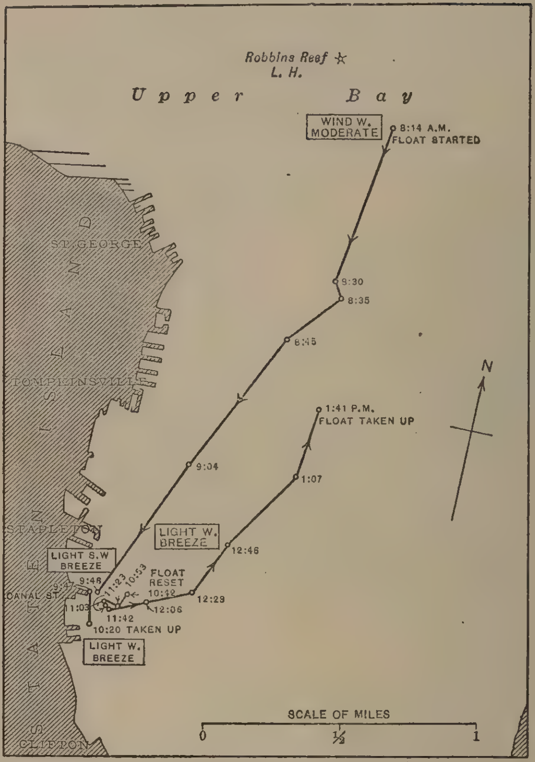
Paths of Floats in the Upper Bay



Total distance covered on ebb	7.53 mi.
Average velocity during ebb	1.37 mi. per hr.
Maximum velocity during ebb	3.14 mi. per hr.
H.W.G.I.	7.39 A.M.
L.W.G.I.	2.00 P.M.

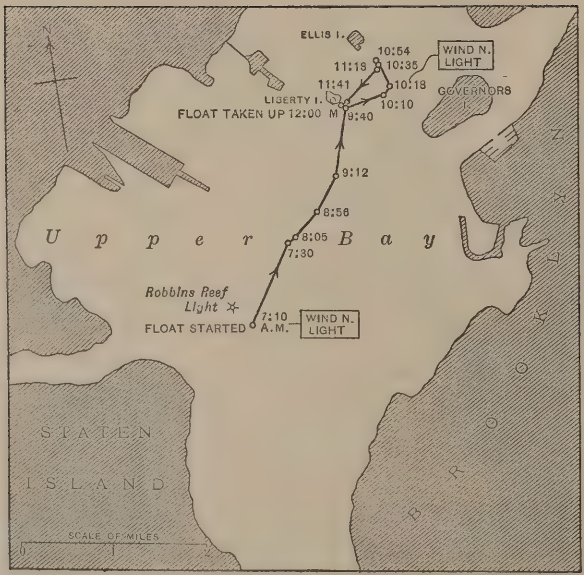
Note: Dist. that would have been covered from 2.21 to 3.06 P.M. est'd at 0.70 mi.

FLOAT 32, SEPT. 25, 1908



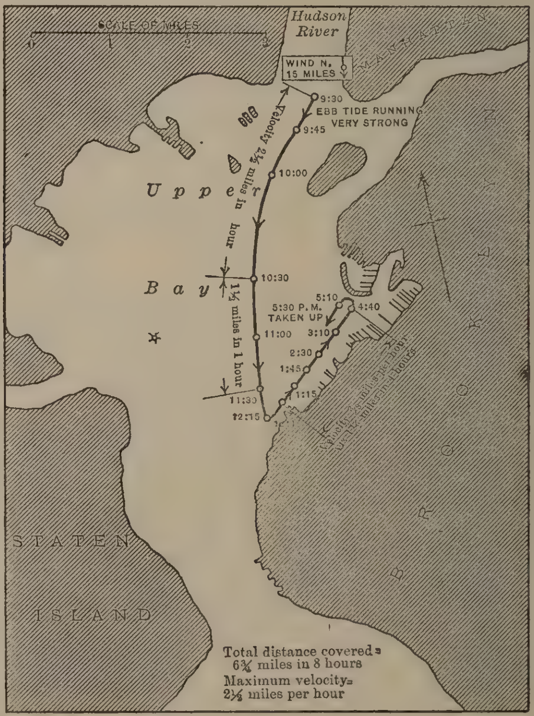
FLOAT 30, SEPT. 18, 1908

Total distance, flood, =1.2 miles in 2.63 hours
Average velocity.... =0.46 miles per hour
Maximum " .... =1.03 " " "
Total distance, ebb, =2.23 miles in 3.08 hours
Average velocity.... =0.72 miles per hour
Maximum " .... =2.25 " " "



FLOAT 33, SEPT. 26, 1908

Total distance, flood, =3.33 miles in 3.73 hours
Average velocity.... =0.89 miles per hour
Maximum " .... =2.82 " " "

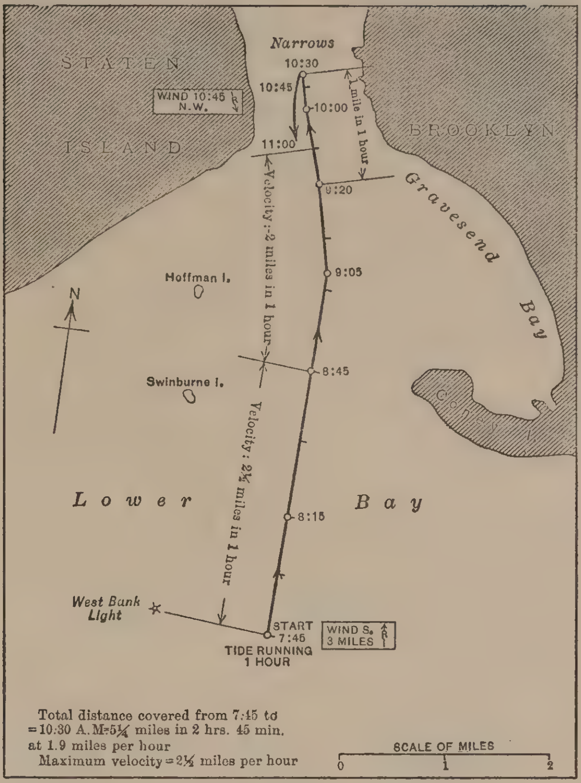


Total distance covered = 6¾ miles in 8 hours
Maximum velocity = 2⅓ miles per hour

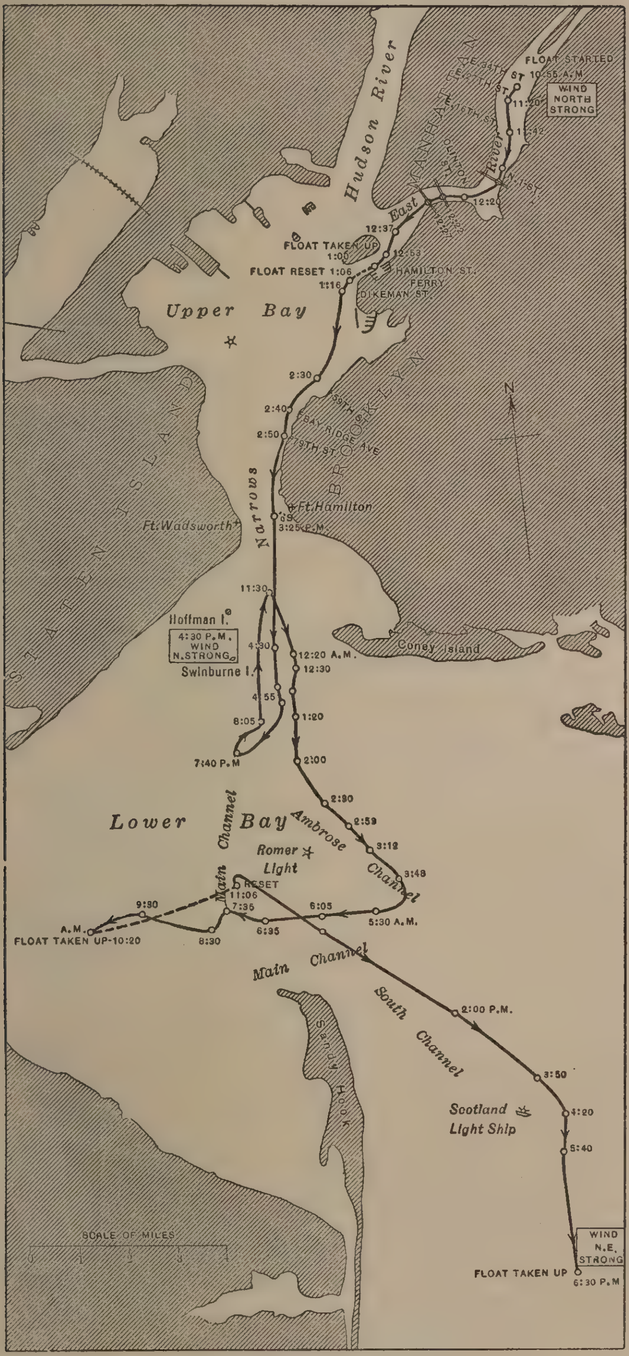
FLOAT P, APRIL 6, 1907

Total distance, flood, =1.69 miles in 4.5 hours
Average velocity.... =0.38 miles per hour
Maximum " .... =0.38 " " "
Total distance, ebb, =4.25 miles in 2.75 hours
Average velocity.... =1.55 miles per hour
Maximum " .... =2.5 " " "

Paths of Floats in the Upper Bay

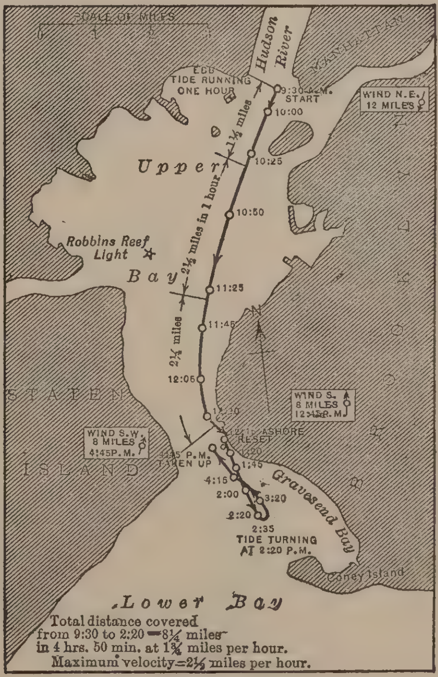


FLOAT S, APRIL 13, 1907



FLOAT 55, NOV. 29-30, 1909

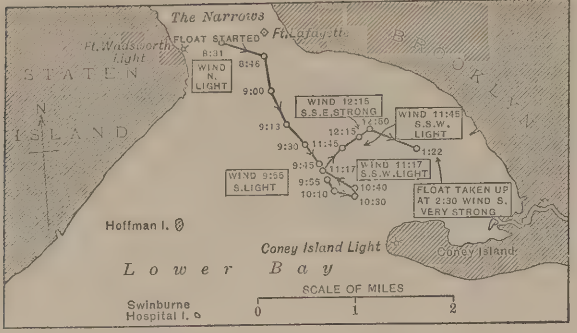
Total distance, flood, = 10.71 miles in 10.27 hours
Average velocity . . . . = 1.04 miles per hour
Maximum " . . . . = 2.4 " " "
Total distance, ebb, = 33.44 miles in 20.16 hours
Average velocity . . . . = 1.66 miles per hour
Maximum " . . . . = 5.7 " " "



FLOAT I, MAR. 25, 1907

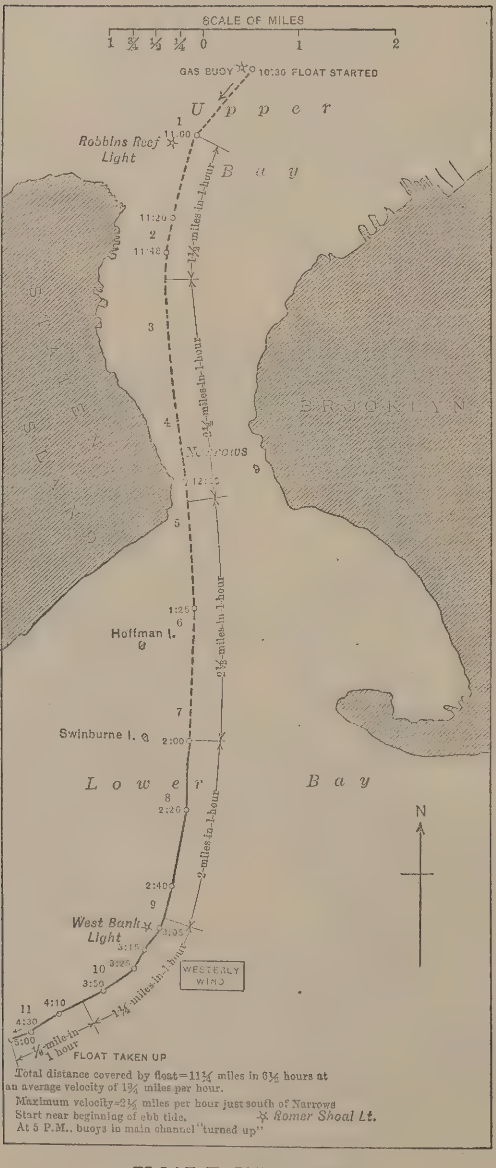
Total distance, flood, = 1.75 miles in 2.42 hours
Average velocity . . . . = 0.72 miles per hour
Maximum " . . . . = 1.25 " " "

Paths of Floats in the Upper and Lower Bays



FLOAT 21, SEPT. 4, 1908

Total distance, ebb, =2.37 miles in 1.98 hours
Average velocity.... =1.2 miles per hour
Maximum " .... =1.75 " " "



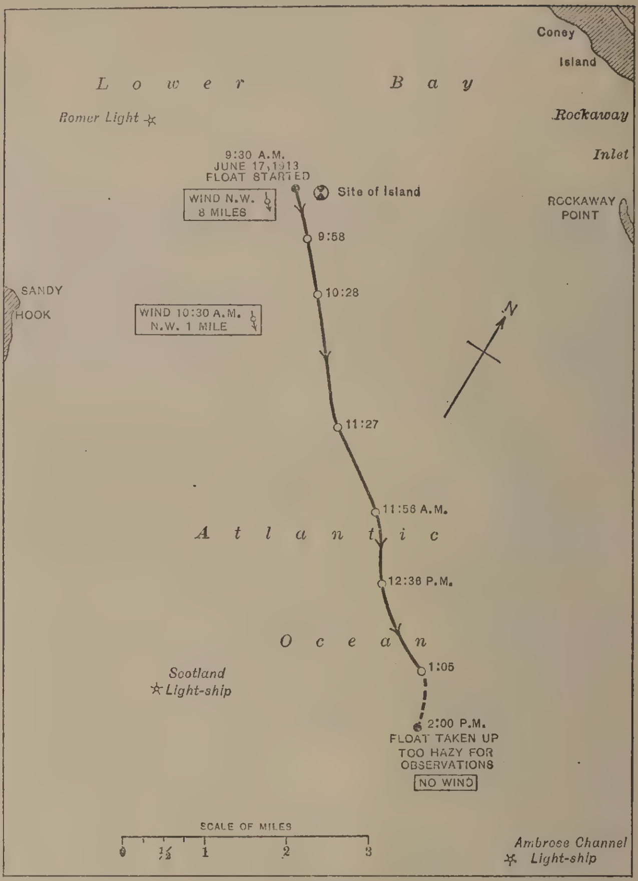
Total distance covered by float=11¼ miles in 6½ hours at an average velocity of 1¾ miles per hour.

Maximum velocity=2½ miles per hour just south of Narrows

Start near beginning of ebb tide.

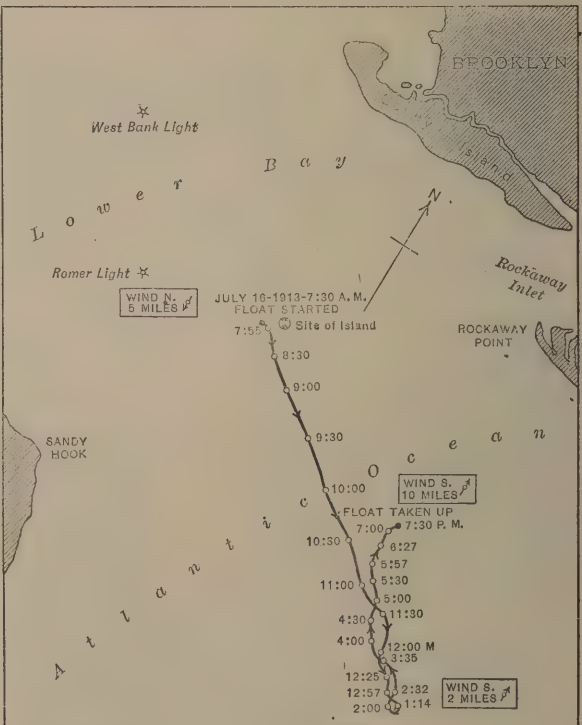
At 5 P.M., buoys in main channel "turned up"

FLOAT U, JULY 8, 1907



FLOAT 70, JUNE 17, 1913

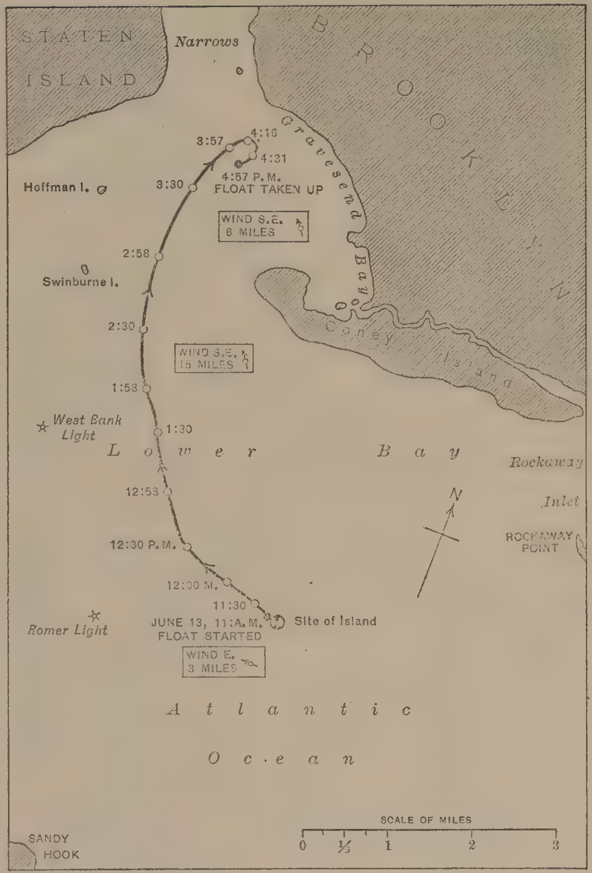
Total distance, ebb, =4.13 miles in 5.0 hours
Average velocity... =0.83 miles per hour
Maximum " ... =1.17 " " "



FLOAT 82, JULY 16, 1913

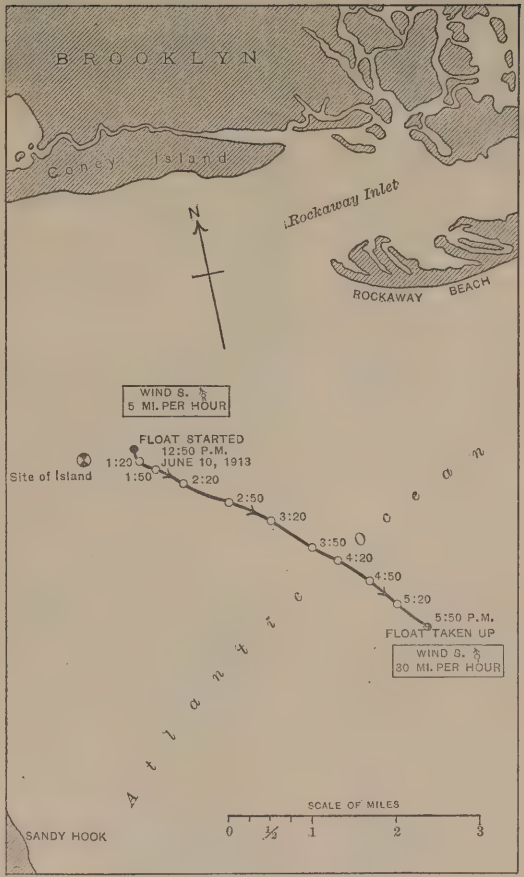
Total distance, flood, =2.84 miles in 5.93 hours
Average velocity.... =0.48 miles per hour
Maximum " .... =0.63 " " "
Total distance, ebb, =6.0 miles in 6.07 hours
Average velocity.... =0.99 miles per hour
Maximum " .... =1.62 " " "

Paths of Floats in the Lower Bay



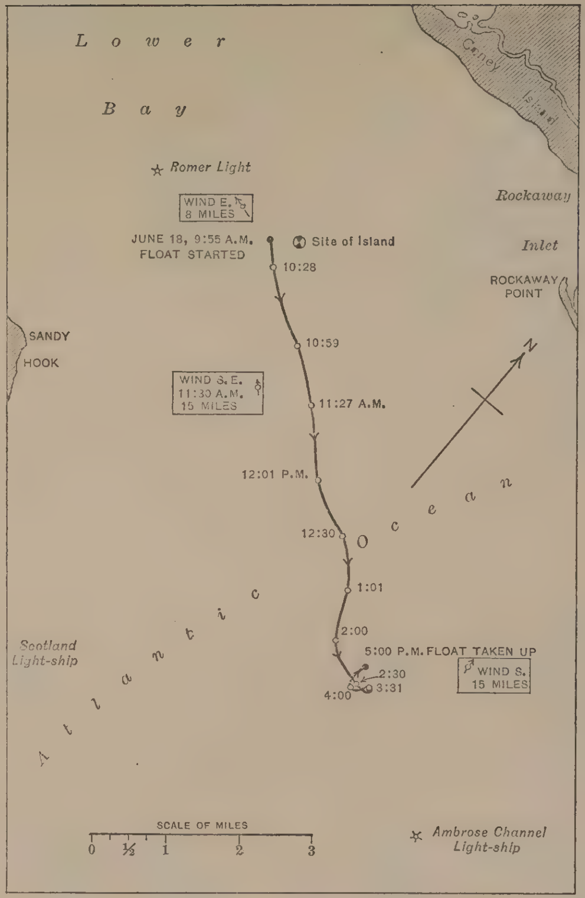
FLOAT 68, JUNE 13, 1913

Total distance, flood, =6.63 miles in 5.27 hours
Average velocity . . . . =1.26 miles per hour
Maximum " . . . . =1.83 " " "



FLOAT 66, JUNE 10, 1913

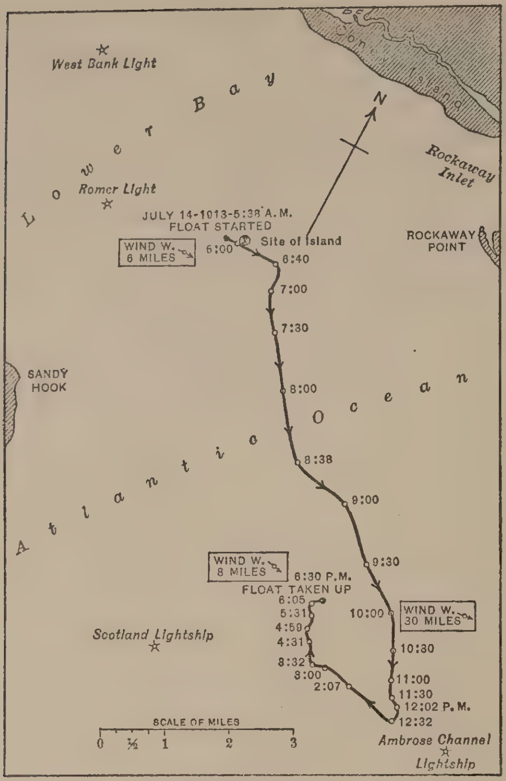
Total distance, ebb, =4.13 miles in 5.0 hours
Average velocity . . . =0.83 miles per hour
Maximum " . . . =1.17 " " "



FLOAT 71, JUNE 18, 1913

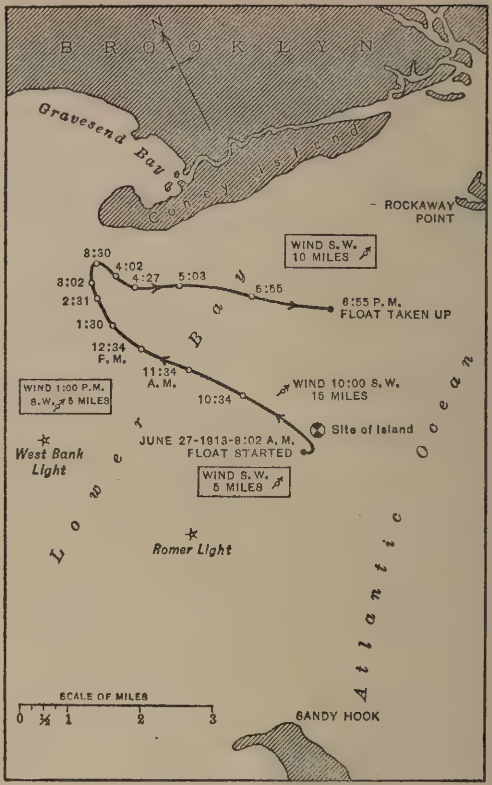
Total distance, ebb, =6.44 miles in 5.6 hours
Average velocity . . . =1.15 miles per hour
Maximum " . . . =2.14 " " "

Paths of Floats in the Lower Bay



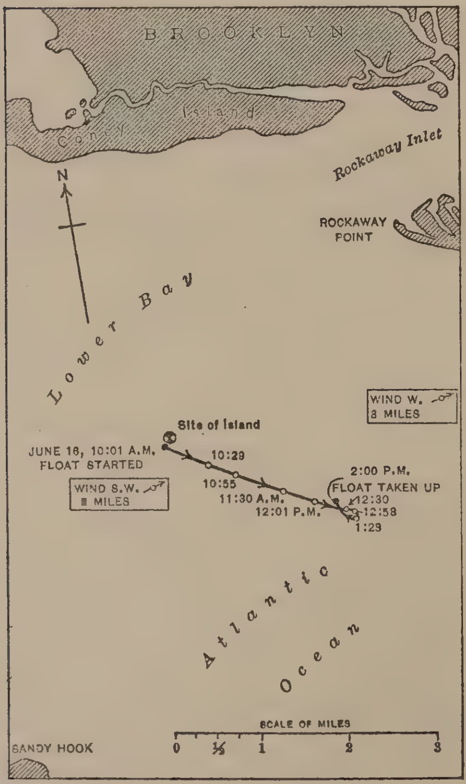
FLOAT 81, JULY 14, 1913

Total distance, flood, =2.78 miles in 6.23 hours
Average velocity.... =0.45 miles per hour
Maximum " .... =0.71 " " "
Total distance, ebb, =8.34 miles in 6.63 hours
Average velocity.... =1.26 miles per hour
Maximum " .... =2.08 " " "



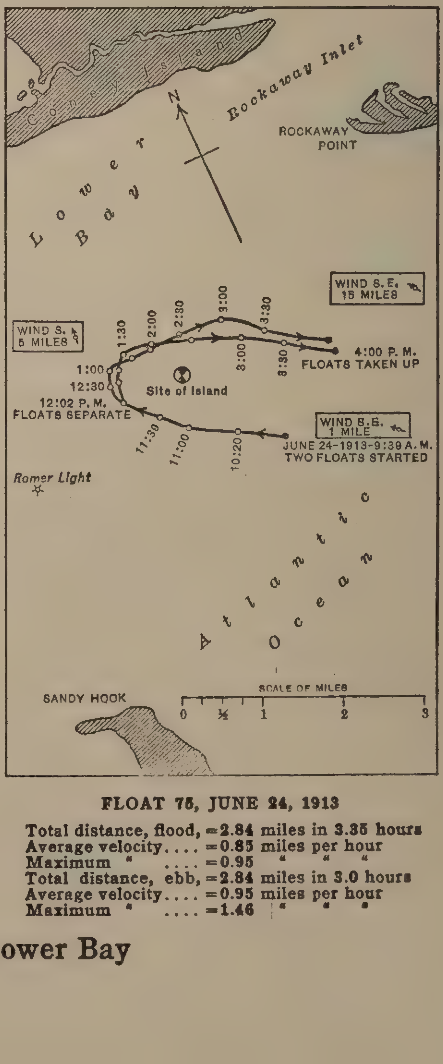
FLOAT 77, JUNE 27, 1913

Total distance, flood, =4.42 miles in 7.47 hours
Average velocity.... =0.59 miles per hour
Maximum " .... =0.82 " " "
Total distance, ebb, =3.42 miles in 3 42 hours
Average velocity.... =1.0 miles per hour
Maximum " .... =1.16 " " "



FLOAT 69, JUNE 16, 1913

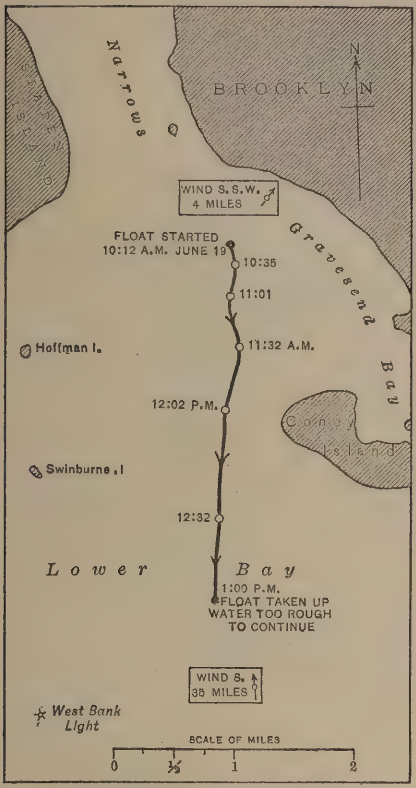
Total distance, ebb, =2.37 miles in 3.45 hours
Average velocity.... =0.69 miles per hour
Maximum " .... =1.26 " " "



FLOAT 75, JUNE 24, 1913

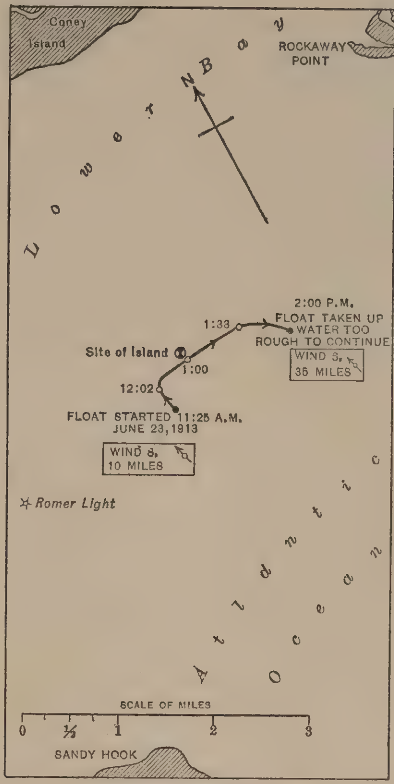
Total distance, flood, =2.84 miles in 3.35 hours
Average velocity.... =0.85 miles per hour
Maximum " .... =0.95 " " "
Total distance, ebb, =2.84 miles in 3.0 hours
Average velocity.... =0.95 miles per hour
Maximum " .... =1.46 " " "

Paths of Floats in the Lower Bay



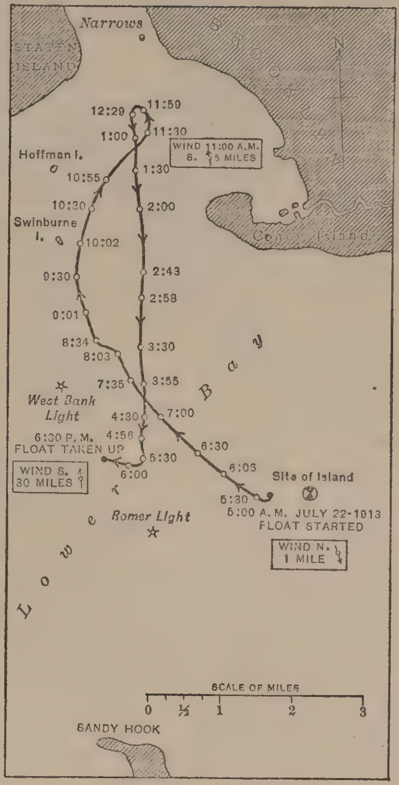
FLOAT 72, JUNE 19, 1913

Total distance, ebb, =2.84 miles in 2.8 hours
Average velocity.... =1.02 miles per hour
Maximum " .... =1.51 " " "



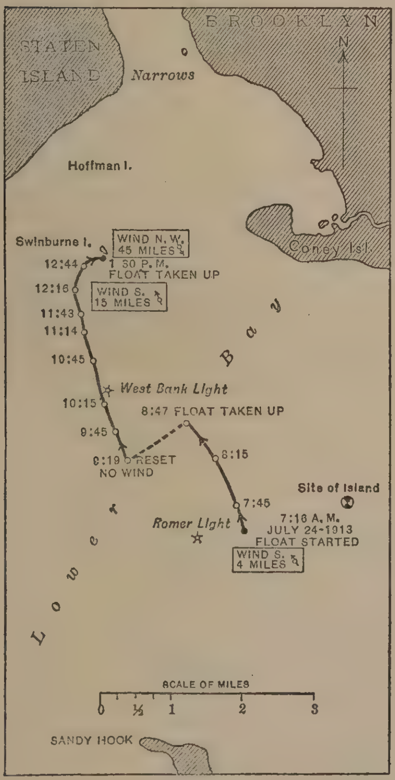
FLOAT 74, JUNE 23, 1913

Total distance, flood, =0.32 miles in 0.62 hours
Average velocity.... =0.52 miles per hour
Maximum " .... =0.52 " " "
Total distance, ebb, =1.70 miles in 1.97 hours
Average velocity.... =0.86 miles per hour
Maximum " .... =1.28 " " "



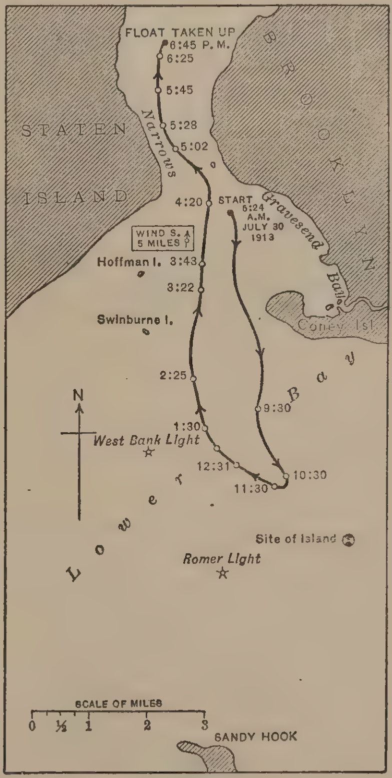
FLOAT 83, JULY 22, 1913

Total distance, flood, =6.60 miles in 6.98 hours
Average velocity.... =0.95 miles per hour
Maximum " .... =1.47 " " "
Total distance, ebb, =4.74 miles in 5.52 hours
Average velocity.... =0.86 miles per hour
Maximum " .... =1.19 " " "



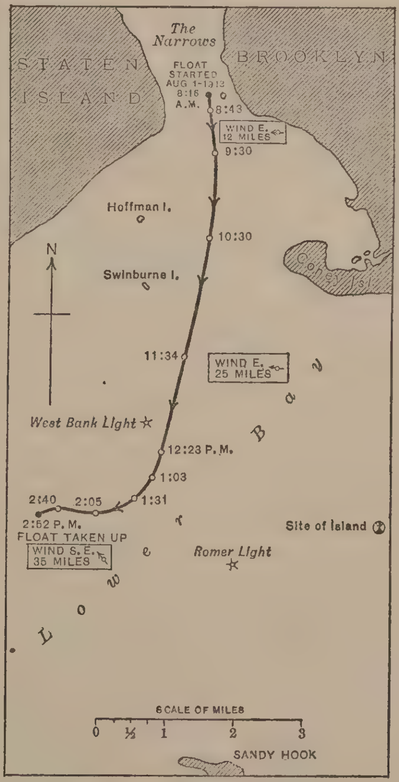
FLOAT 84, JULY 24, 1913

Total distance, flood, =4.74 miles in 5.70 hours
Average velocity.... =0.83 miles per hour
Maximum " .... =1.52 " " "



FLOAT 87, JULY 30, 1913

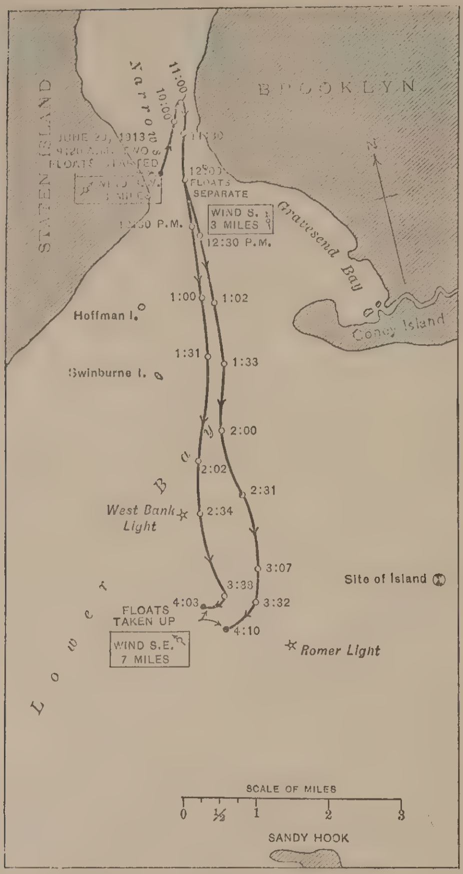
Total distance, flood, =8.52 miles in 8.25 hours
Average velocity.... =1.03 miles per hour
Maximum " .... =1.63 " " "
Total distance, ebb, =4.61 miles in 4.1 hours
Average velocity.... =1.13 miles per hour
Maximum " .... =1.20 " " "



FLOAT 88, AUG. 1, 1913

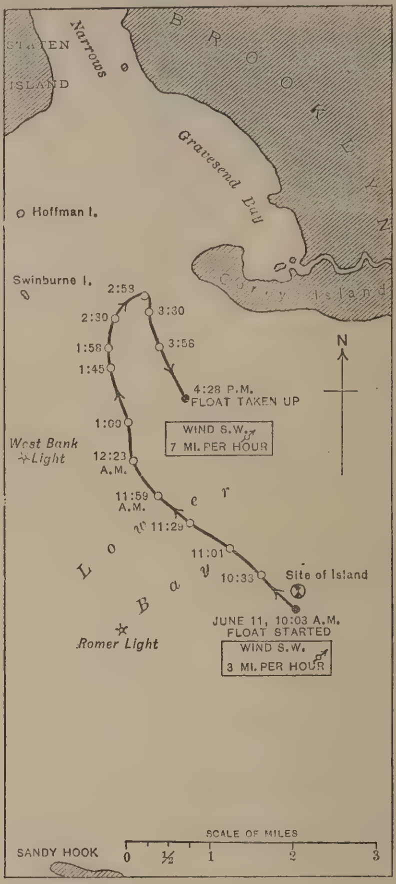
Total distance, flood, =1.33 miles in 1.35 hours
Average velocity.... =0.99 miles per hour
Maximum " .... =0.99 " " "
Total distance, ebb, =5.93 miles in 5.25 hours
Average velocity.... =1.13 miles per hour
Maximum " .... =1.59 " " "

Paths of Floats in the Lower Bay



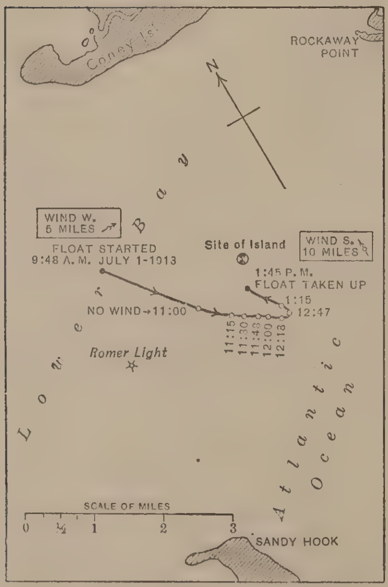
FLOAT 73, JUNE 20, 1913

Total distance, ebb, =**7.45** miles in **5.17** hours
Average velocity.... =**1.44** miles per hour
Maximum " .... =**2.03** " " "



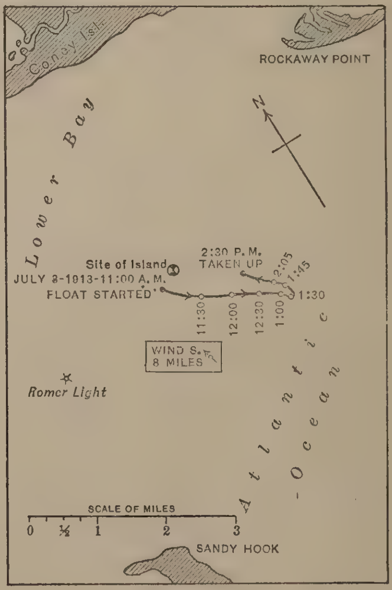
FLOAT 67, JUNE 11, 1913

Total distance, flood, =**4.86** miles in **4.92** hours
Average velocity.... =**0.99** miles per hour
Maximum " .... =**1.14** " " "
Total distance, ebb, =**1.32** miles in **1.5** hours
Average velocity.... =**0.88** miles per hour
Maximum " .... =**1.36** " " "



FLOAT 78, JULY 1, 1913

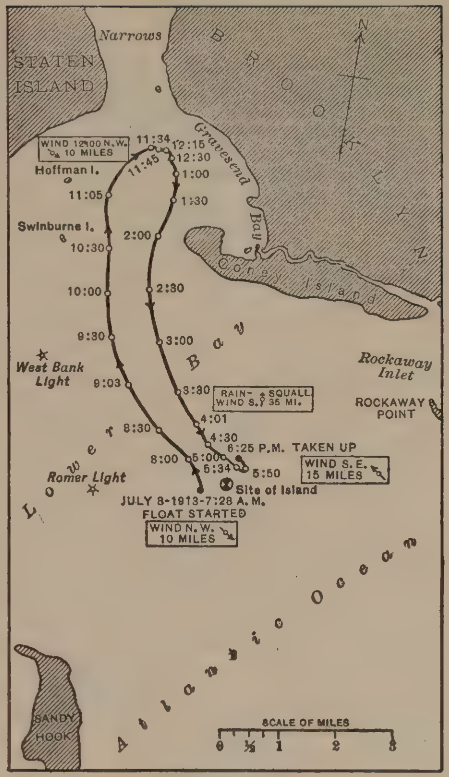
Total distance, flood, =**0.76** miles in **0.97** hours
Average velocity.... =**0.78** miles per hour
Maximum " .... =**1.05** " " "
Total distance, ebb, =**3.03** miles in **2.97** hours
Average velocity.... =**1.02** miles per hour
Maximum " .... =**1.77** " " "



FLOAT 79, JULY 3, 1913

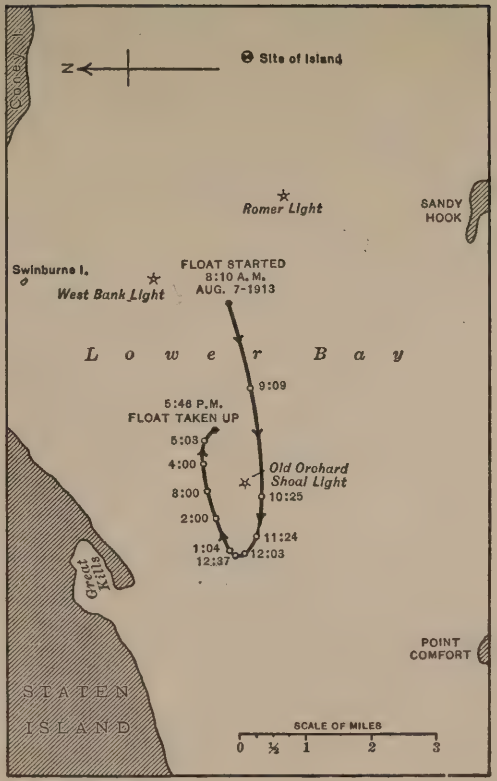
Total distance, flood, =**0.79** miles in **1.0** hour
Average velocity.... =**0.79** miles per hour
Maximum " .... =**1.12** " " "
Total distance, ebb, =**1.89** miles in **2.5** hours
Average velocity.... =**0.76** miles per hour
Maximum " .... =**1.20** " " "

Paths of Floats in the Lower Bay



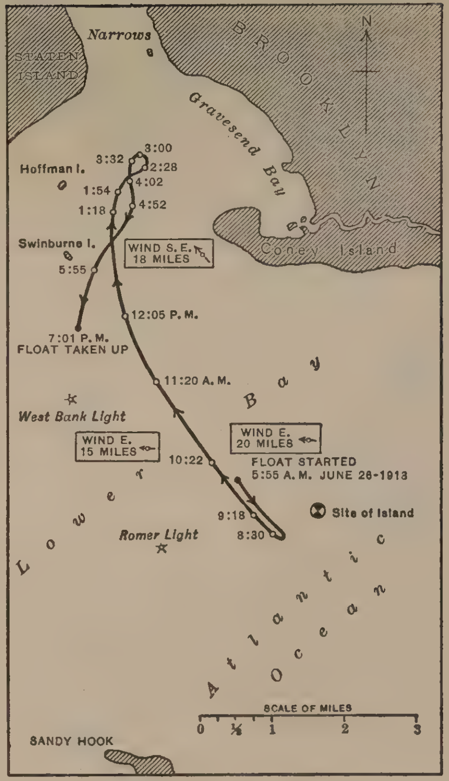
FLOAT 80, JULY 8, 1913

Total distance, flood, =6.44 miles in 4.53 hours
Average velocity.... =1.41 miles per hour
Maximum " .... =1.79 " " "
Total distance, ebb, =6.0 miles in 5.5 hours
Average velocity.... =1.09 miles per hour
Maximum " .... =1.78 " " "



FLOAT 90, AUG. 7, 1913

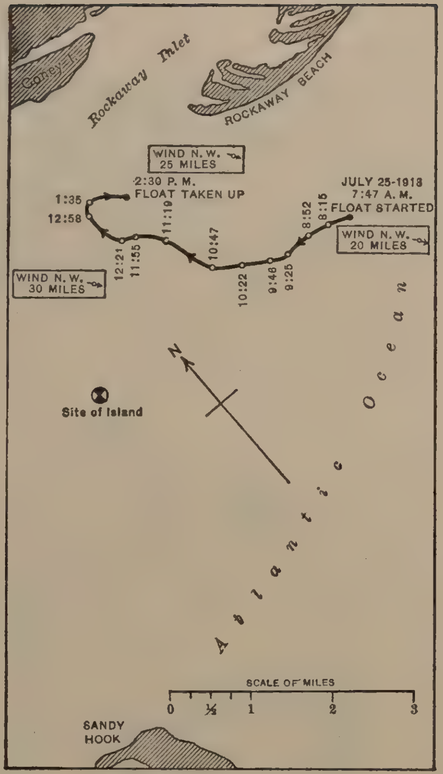
Total distance, flood, =3.92 miles in 3.88 hours
Average velocity.... =1.01 miles per hour
Maximum " .... =1.35 " " "
Total distance, ebb, =2.21 miles in 5.72 hours
Average velocity.... =0.39 miles per hour
Maximum " .... =0.61 " " "



FLOAT 76, JUNE 26, 1913

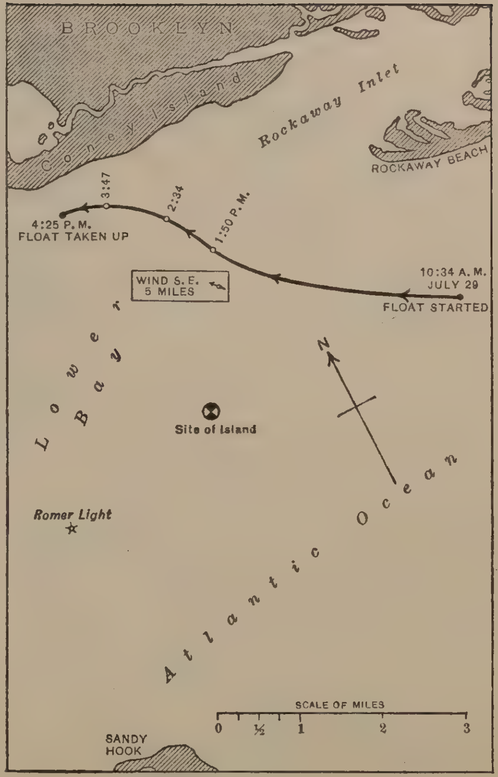
Total distance, flood, =6.0 miles in 7.0 hours
Average velocity..... =0.86 miles per hour
Maximum " ..... =1.42 " " "
Total distance, ebb,.. =2.53 miles in 4.0 hours
Average velocity..... =0.63 miles per hour
Maximum " ..... =0.92 " " "

Paths of Floats in the Lower Bay



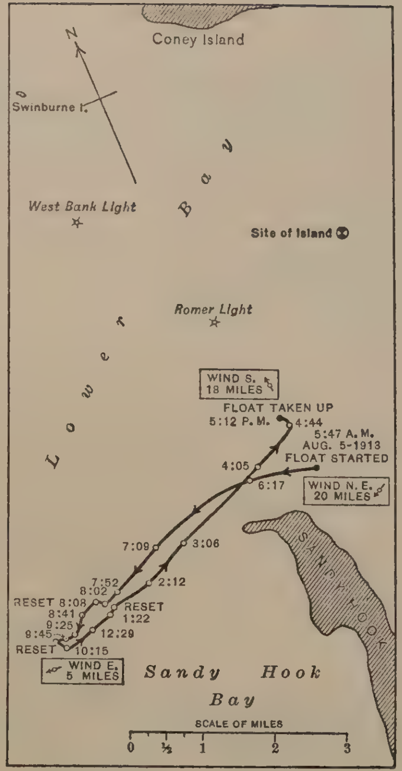
FLOAT 85, JULY 25, 1913

Total distance, flood, =3.50 miles in 5.80 hours
Average velocity.... =0.60 miles per hour
Maximum " .... =1.19 " " "
Total distance, ebb, =0.38 miles in 0.93 hours
Average velocity.... =0.41 miles per hour
Maximum " .... =0.41 " " "



FLOAT 86, JULY 29, 1913

Total distance, flood, =5.05 miles in 5.85 hours
Average velocity.... =0.86 miles per hour
Maximum " .... =0.96 " " "



FLOAT 89, AUG. 5, 1913

Total distance, flood, =4.33 miles in 3.87 hours
Average velocity.... =1.12 miles per hour
Maximum " .... =1.89 " " "
Total distance, ebb, =4.73 miles in 6.78 hours
Average velocity.... =0.70 miles per hour
Maximum " .... =1.45 " " "

Paths of Floats in the Lower Bay

CHAPTER V

TIDAL INFORMATION IN POSSESSION OF THE COMMISSION AND CORRESPONDENCE ON THIS SUBJECT WITH THE UNITED STATES COAST AND GEODETIC SURVEY

TIDAL STUDIES

In the Commission's first report, issued in April, 1910, considerable space was given to a discussion of the tidal phenomena in the metropolitan district, and this information was considered to have value not only in the disposal of the sewage, but to shipping and other interests.

Owing to the fact that the methods of calculation employed have never been fully explained, in view of some corrections which have had to be made in the published records of the Commission and because of the importance which properly attaches to the information, it seems desirable here briefly to make such explanations and corrections as may be necessary in order to reconcile the data and to explain how some of the most important particulars were derived.

The principal and hydrographic features of the harbor were discussed in the 1910 report together with the principal current phenomena and the phenomena of discharge. Attention was given to the flow of land and sea water entering the harbor, the volumes of water in the harbor, and the tidal ranges. Finally, included in this discussion, reference was made to the effects of winds, dredgings, obstructions and bulkheads upon the tidal flow. This information is contained in the Report of April, 1910, Part III, Chapter III.

Supplementing the discussion of the tidal phenomena, the report of 1910 contains a chapter on the harbor currents as shown by floats. The float work included a considerable number of observations of can and spar floats which were set adrift and observed for long periods of time, occasionally for several days, in various parts of the harbor. The information in regard to this float work is contained in Part III, Chapter IV of the Report of April, 1910.

During the course of a full year, observations of the salinity of the waters were made at eleven stations in the harbor, the object being to supplement the information obtained from other sources as to the tidal phenomena and indicate the changes in the proportions of sea and land water present at different tides and seasons at widely separated points. For the purposes of this work a special apparatus was devised and a large number of observations made. The results were published in the report of 1910, Part III, Chapter XIII. The proportions of land water and sea water are indicated by means of tables and a diagram. The original observations were too voluminous for publication.

Hydrographic information in addition to that published in the 1910 report has been issued by the Commission in its report of August, 1912, and in some of its preliminary reports. The divisions of the harbor with their areas were given in the 1912 report together with a discussion of the volumes and circulation of the water. (See Part I, Chapter II.)

The volumes of water in the several divisions during low tide, the water in the tidal prism and the resultant ebb flow were stated in Preliminary Report VI, issued February, 1913.

In Chapter IV, Part IV of this report, there is a description of the tidal currents in the harbor as shown by the float records which the Commission considers sufficiently reliable to be used as a basis for calculations.

Explanation of Methods Employed

Tidal Volumes.—The tidal volumes as published in the Commission's 1910 report, and subsequently, are based upon a theoretical investigation made by the U. S. Coast and Geodetic Survey in response to the Commission's request. The results are contained in a letter from the Survey to the Commission dated August 14, 1908.

The method of computation consisted of first determining the mean cross-sectional area of the tidal channel under consideration, and then correcting to mean conditions the average of the maximum observed velocities for flood and ebb currents in this section according to the ratio which the tidal range during the observations bore to the mean range. If the flow is hydraulic, due to difference of head (as between Long Island sound and the Upper bay) instead of to progressive wave action, the correction is made according to the ratio of the square roots of the respective ranges. To this velocity is then applied a factor (about 0.75) reducing the maximum velocity to the mean in the section at the strength of the current; a second factor, $\frac{2}{\pi}$, is then applied, reducing the velocity at the strength of current to the mean velocity for the duration of flow (this upon the assumption that the velocity curve is a true sine curve). Finally, the product of this velocity by the cross-sectional area by the number of seconds in six lunar hours gives the average volume of the flood or ebb flow.

If there is an ebb excess, half this amount is deducted from and half added to the volume as above computed, to obtain the flood and ebb volumes, respectively. The ebb excess of the Hudson and Kill van Kull is due to land water discharge, which quantity is obtained from rainfall records. The ebb excesses of the East river and Harlem river are chiefly due to hydraulic conditions. The ebb excess of the Narrows is the total land water discharge and the excess of the East river.

In recalculating the results the Survey's method was slightly modified by the Commission in that flood and ebb volumes were computed separately, the actual durations of the flood and ebb currents were used, and an attempt was made, from records of previous observations, to obtain a reliable factor for reducing the maximum velocity in a cross-section to the mean. The modified method, while an improvement upon that described before, is still faulty, in that the reduction factor is sometimes based upon meagre information and is constant, whereas observations of the U. S. Engineers in Hell Gate and vicinity indicate that this factor changes continually during each current.

The tidal volumes computed in this manner were published in the Commission's report of April 30, 1910, page 178, and again in the report of August 1, 1912, and in the absence of reliable gaugings, they must be regarded as representing the most authentic information available.

The areas at mean low water of the various divisions of the harbor were computed in the office of the Commission from the Coast Survey charts. Each area was carefully measured by a planimeter, and was taken as the mean of several readings. Care was taken to use the actual, instead of the nominal scale of the charts, the correction factor being the ratio between the measured length of the engraved linear scale and its nominal length as computed by the representative fraction. The figures thus obtained were published in the report of April 30, 1910. Before the publication of the 1912 report, however, it was discovered that the former measurements had been taken to the high water contour instead of to that of low water. The areas were therefore recomputed and published, August 1, 1912.

The tidal prism is the volume of water normally lying above the plane of mean low water and high tide. It is equal to the product of the area at mean tide level by the mean range of tide. For the various divisions of the harbor, the tidal prism was computed in the office of the Commission, using the mean range of tide as given by the Coast Survey, and an average of the areas at mean low water and mean high water. In some parts of the harbor, such as the Upper East river, Harlem river, and Jamaica bay the difference between these areas is great, while in the lower East river, Hudson river, Upper bay, Kill van Kull and Arthur Kill, it is almost negligible, and the tidal prism may be taken as the product of the mean low water area by the mean range of tide. In Newark bay the difference is appreciable, but not great.

The volume below mean low water was originally computed by the Commission by two methods. For the large, open bodies of water such as the Upper bay, the surface of the chart was divided into small squares, and from the soundings the average depth and volume were obtained for each square. For the river channels, cross-sections were taken at regular intervals upon the chart, their areas determined, and the intervening volume found by average end areas.

In the original computations of the Commission, the East river was considered in three sections, divided at 88th Street and at Old Ferry Point. Data for the East river, arranged for this division, was published in the report of April 30, 1910.

Before the publication of the report of 1912 the classification was changed, and in this report the data is tabulated for the Upper and the Lower East river, two divisions only, divided at 88th Street. More recently the line of division has been considered as located at Lawrence Point, necessitating a recomputation of data.

A new method was employed for determining the volume below mean low water. The area of each contour, from that of mean low water to the greatest depth, was measured by a planimeter, two sets of measurements being taken to insure accuracy. The contour interval assumed was six feet for the first sixty feet of depth, and ten feet for greater depths. These areas were then combined by the prismoid formula to determine the volume.

The summation of volumes for the total East river were at variance with former estimates and it was deemed advisable to revise the computations of other divisions in which the dilution factor was of importance. Consequently the volume, tidal prism, etc., of Jamaica bay and the Harlem river were recomputed, and results varying from previous determinations were obtained. These revised figures were published in Preliminary Report No. VI, Metropolitan Sewerage Commission, February, 1913.

The average depth is the quotient of the volume below mean low water divided by the mean low water area.

The complete tidal data in possession of the Commission, as corrected to the latest information, and as used in the latest computations, is given in a table attached to this report. All these data have, at one time or another, appeared in the publications of the Commission.

The values given for the mean low water area, tidal prism, and volume below mean low water are the result of careful measurements and computations from the Coast Survey Charts.

TABLE CIV

Division	Area M.L.W. square miles	Average tidal range, feet	Tidal prism, million cubic feet	Average depth, feet	Volume below M.L.W. million cubic feet	Section	Ebb volume, million cubic feet	Flood volume, million cubic feet	Ebb excess, million cubic feet
1. Upper bay	19.51	4.4	2,541	23.9	12,970	Narrows	12,773	11,490	1,283
2. Hudson river (below Mt. St. Vincent)	14.49	4.2	1,697	30.5	12,330	Battery	6,722	5,635	1,087
3. Upper East river (above Lawrence Pt.)	9.23	7.0	1,869	21.4	5,512	Lawrence Pt.	*(3,654)	*(3,539)	**(115)
4. Lower East river	4.24	4.7	552	35.4	4,174	Battery	4,068	3,968	100
5. Harlem river (above 101st street)	0.77	5.5	148	13.3	285	High Bridge	176	161	15
6. Kill van Kull	1.03	4.8	150	25.3	728	Const. Point	1,479	1,391	88
7. Newark bay	8.06	4.6	1,071	6.9	1,542	Mouth	1,972	1,867	105
8. Arthur Kill	4.16	5.4	743	15.0	1,735	Upper End	330	297	33
9. Jamaica bay	20.93	4.3	2,309	3.9	2,258	Rockaway Pt.	1,989	1,965	24
10. Lower New York bay	122.75	4.9	16,765	....	....	ConeyIs.-Sandy Hook.	24,658	23,323	1,335

*Is equal to East river discharge past Battery, less the tidal prism of the Lower East river, plus the flow of the Harlem river past Willis avenue.

**Differs from ebb excess of Lower East river by amount of ebb excess in Harlem river.

CORRESPONDENCE WITH THE UNITED STATES COAST AND GEODETIC SURVEY IN REGARD TO THE TIDAL PHENOMENA

In the five years previous to May, 1913, a considerable amount of correspondence was exchanged between the Metropolitan Sewerage Commission and the U. S. Coast and Geodetic Survey with regard to questions upon which the Survey was properly regarded as an authority. These questions related to the flow of water in and out of the principal parts of New York harbor, especially to the estimates of quantity of water passing seaward in excess of the flow in the opposite direction, this subject being of much importance as indicating the extent to which the sewage of New York could be carried mechanically to sea. It is believed that the most important part of this correspondence should be published in full.

There is the more reason for publishing this correspondence in the fact that some of the leading problems raised had previously received a different solution by the Survey. This is notably true of the resultant flow of water in the Lower East river. Until the opinions here published were expressed, it was believed that there was a considerable preponderance of water flowing southward through the East river in excess of that which passed northward under the tidal influences. The Survey statements here given must be accepted as superseding the earlier estimates. The latest opinion is that there is little or no excess flow in either direction.

The correspondence is divisible into three principal parts.

Part I relates to the tidal flow in the various parts of the harbor and especially to the excess or resultant discharge in one direction over the reverse flow.

Part II relates to new estimates by the Commission of the flow of the East river, based on data collected under the direction of Colonel William M. Black, Corps of Engineers, U. S. A.

Part III is concerned with the probable stability of an artificial island which the Commission has proposed for the disposal of a large amount of sewage at the ocean entrance of the harbor.

SECTION I

CORRESPONDENCE RELATING TO THE TIDAL FLOW

At the outset of its work in 1908, the Commission recognized the need of a comprehensive knowledge of the quantities of water flowing in each direction through the principal divisions of the harbor and contemplated the collection of the necessary data by means of a hydrographic survey. Before undertaking this work, it was thought desirable to ascertain from the Survey what instruments and methods were, in the Survey's opinion, most serviceable for this undertaking. With this object in view, the following letter, marked Exhibit I, was sent under date of May 8, 1908.

EXHIBIT I

New York, May 8, 1908.

Director,
U. S. Coast & Geodetic Survey,
Washington, D. C.

Dear Sir: Will you kindly send me such information either in the form of descriptions or references as may be available concerning methods and apparatus for gauging very large streams such as tidal currents of harbors and the flow of great rivers like the Hudson in the vicinity of New York City?

Very sincerely,
George A. Soper,
President.

On May 27, 1908, a reply was received describing meters and other apparatus which had been used in various studies made in previous years of the tidal phenomena of New York harbor. The letter also contained an epitome of results for the discharge of four of the principal sections of New York harbor. The quantities of water given in this epitome represent the information which has been used by the Survey for the last 22 years.

It is noteworthy that the volumes of water reported as being discharged through the different parts of New York harbor were based on a series of precise levels which were run for the connection of tide gauges.

Subsequent to the studies which had led to the results given in the epitome, current observations were made covering 40 different stations over a period of two months.

This letter from the Coast Survey indicated that a considerable amount of study had been given to the tidal phenomena of New York harbor and suggested to the Commission that it would be desirable before taking up new work to obtain a digest from the Survey of all existing facts relating to the specific problems which the Commission desired information upon. The letter, describing apparatus, containing the epitome and the other information here referred to, follows as Exhibit II.

EXHIBIT II

WASHINGTON, D. C., May 27, 1908.

MR. GEORGE A. SOPER,
President, Metropolitan Sewerage Commission of New York.

DEAR SIR: In reply to your letter of May 8, 1908, requesting information concerning methods and apparatus for gauging very large streams, such as tidal currents of harbors and the flow of great rivers like the Hudson in the vicinity of New York City, I will state that in the New York harbor gauging operations made by the Coast and Geodetic Survey in the eighties, electric current meters were principally used to determine the velocities. The meters were manipulated from ships and launches anchored at the place where the velocities were to be taken.

The meters were lowered to the desired depth by means of a wire rope, inside of which was an insulatd core containing two copper wires by which the revolutions of the wheel of the meter were registered on a recording apparatus on deck.

As the weight attached to the meter has to be heavy (60 to 100 lbs.) in strong sub-surface currents, the lowering rope was manipulated by a reel placed on deck. This reel was so devised that the unwinding and winding up of the rope on the drum of the reel did not interfere with the electric current passing from the meter to the recording apparatus.

The drum was also made of such diameter that the number of revolutions of the drum indicated the distance the meter was below the surface of the water.

Both the Price and Haskell current meters were used in the New York Harbor work.

The Price Current Meter is manufactured by the Gurley's of Troy, N. Y. Their last manual, 40th edition, gives considerable information in regard to this meter and other matter pertaining to the manipulation of a current meter.

The Haskell Meter was, and I think still is, manufactured by Ritchie Bros., of Brookline, Mass. They also manufacture the Ritchie-Haskell Current-direction Meter. This latter instrument, in addition to registering the current, also gives the direction of the current at the same time. This latter information is very desirable at times and most important in gauging the Hudson river in the vicinity of New York City.

Our observations showed that at certain times and stages of the tide, the under-run of the flood is very evident. This phenomenon was observed at the Narrows—opposite 39th street on the Hudson—and I think up as far as Dobbs Ferry. (See Appendix No. 15, C. & G. S. Report, 1887.) For the gauging of New York Harbor in 1885, current observations were made at seven discharge sections, viz.: one in Arthur Kill near Elizabethport, one in Kill van Kull near West New Brighton, one in the Narrows, one in East river at 19th Street, and one at Old Ferry Point, one at 39th Street, Hudson river, and one at Dobbs Ferry, Hudson river.

Tide gauges were maintained at each of the above sections during the period of the current observations at least, and at Governor's Island and Sandy Hook, at Elm Park and Elbow Beacon on Newark Bay, Hell Gate Ferry, Pot Cove and Willet's Point on East river, and Ossining and Iona Island on the Hudson. In addition, current observations were also made on the outer slope of New York Bar.

Six of the vessels of the Survey, together with steam launches and boats, their officers, crews and additional current and tidal observers, were employed during the season's work.

The principal results of the survey are given in Asst. Henry Mitchell's Report, dated March 24, 1888 (Appendix No. 15, C. & G. S. Report, 1887). The under-run of the Hudson river, densities at different depths, the currents at different times and depths, and the slopes and changes of slope of the Hudson and East rivers are given and discussed. An unpublished report by Asst. E. E. Haskell (June 30, 1886), to Professor Mitchell, gives the reduction of the gaugings, giving the following flood and ebb discharges for the various sections:

TABLE CV

Epitome of Results for Discharge

From observations made between July 28 and Sept. 16, 1886

East river (19th street)	Ebb (Westerly)	4,454,937,257	cubic feet
	Flood (Easterly	4,007,175,676	“ “
Hudson river (39th street)	Ebb (Southerly)	6,996,678,413	“ “
	Flood (Northerly)	6,225,985,545	“ “
Kill van Kull (W. New Brighton)	Ebb (toward the Harbor)	1,790,103,372	“ "
	Flood	1,712,415,362	“ “
Narrows	Ebb (Seaward)	13,819,895,144	“ “
	Flood	12,703,616,481	“ "

In the observations of 1886, having mainly in view the circulation of the waters of the East river through New York Harbor, four current sections were occupied and twenty-five tide stations observed. A series of precise levels was run for the connection of the tide gauges used in the physical hydrography investigation of New York Harbor and vicinity. Professor Mitchell's report (App. 12, Report of 1886) of May 6, 1887, "On the circulation of the sea through New York Harbor," gives the results of this investigation.

Current observations were made at the entrance to New York Harbor during the summer of 1887, covering a period extending from June 20th to August 10th. Forty different stations were occupied during that time and they were taken in successive groups or sets of 3 to 4 simultaneously observed stations; they were taken in Fourteen Ft., East, Swash, Main Ship, Gedney and South Channels. Two vessels, two steam launches of the Survey and the necessary complement of boats and crew were used in the work. Self-registering tide gauges were running at Bath Beach and Sandy Hook during the observations. At 23 of the stations occupied for velocity observations, specimens showing the nature and composition of the bottom were obtained, and it may be of interest to note that the field record of the dredged specimens in the East and Swash Channels describes some of the specimens as "black, sticky ooze or mud, having the smell and appearance of refuse from oil refineries or gas works" and "yellow scum," "yellowish scum," etc.

A report giving the scope of the work, tabulation of all the observed velocities, directions, densities, soundings, dredgings and descriptions of instruments and appliances used is in the archives of the Survey.

Appendix No. 9, Report of 1888, by Assistant Marindin, "Tidal Levels and Flow of Currents in New York Bay and Harbor," demonstrates the movements of the tide in filling and draining the tidal reservoirs surrounding New York City.

In addition to the already mentioned Appendices (No. 9, 1888, and No. 12, 1886, and No. 15, 1887), additional data bearing on the subject will be found in the Survey's Reports for 1856, 1858, 1859, 1866, 1867, 1871 and 1876, and Bulletin No. 8.

The subject of current and discharge measurements has been extensively gone into by the Mississippi River Commission and a great number of observations have been and are still being made by them.

By their present method of taking a discharge of the Mississippi it takes but a few hours to complete the observations. The appliances used comprise a small steamer and one meter outfit. One of the time consuming items they do away with is that they do not anchor, but make the observations while the engineer, with hand on the throttle, keeps the boat on the cross-section by observing a fixed range on shore, care being taken that the beginning and ending of the observation is made when the boat is exactly on range. Likewise the boat is held laterally on the section by the helmsman observing a diagonal range on shore. On completion of the observations, the boat is then rapidly moved to the next station on the cross-section, and so on.

Of course on the Mississippi the current is always down stream, and the change in the velocities are slow during the interval of observation, and a succession of daily observations permits one to eliminate even that small source of error.

By consulting the reports of the Commission, especially those between the years 1881 and about 1886, a considerable amount of detail information in regard to appliances and methods may be obtained. Also a letter to the Secretary of the Commission (1307 Liggett Bldg., St. Louis, Mo.), who has charge of the present observations, may bring some up-to-date information.

Extensive current work was done on the Niagara River a few years ago. Either the U. S. Engineer Reports or the Reports of the International Waterway Commission give some of the details of operation. In recent years the Weather Bureau and the Reclamation Service have also taken up the subject of Current Observation.

Very respectfully,
O. H. Tittmann,
Superintendent.

Upon the receipt of the letter given here as Exhibit II, the Commission requested the Survey to give careful consideration to a list of ten specific questions concerning the volume of water discharging through the different parts of the harbor under conditions which were both usual and unfavorable to a large net outflow toward the sea. The letter described the uses to which this information was to be put and gave the Survey an opportunity to understand the scope and extent to which the detail was desired. This letter, which is dated June 19, 1908, is given here as Exhibit III.

EXHIBIT III

New York, June 19, 1908.

Mr. O. H. Tittmann, Superintendent,
Coast and Geodetic Survey,
Washington, D. C.

My Dear Prof. Tittmann: After giving due consideration to the various subjects discussed at the interviews which Mr. Sooysmith and I had the pleasure of holding with Secretary Straus, and later with you and Mr. Perkins, and in view of the necessities of the work upon which the Metropolitan Sewerage Commission is engaged, it has seemed desirable to form the following list of specific questions as a basis for information which your Survey is requested to supply. In order that you shall have the benefit, so far as possible, of our point of view in requesting this information, there are sent to you, under another cover, a reprint of a paper by one of us on the pollution of New York harbor and the final report of the New York Bay Pollution Commission. The first report of the New York Bay Pollution Commission, containing specific references to data published by your office on tidal phenomena of New York harbor, is sent you at the same time. This is the last copy of this report which is available, the edition having been exhausted several years ago.

The flow of water through New York harbor is interesting to the Metropolitan Sewerage Commission for a number of reasons, chief of which are the following:

The sewage, that is the refuse which is carried by underground pipes and channels from dwellings, manufactories and from the surface of the earth during rain storms, is now discharged into the harbor and its tributaries without restriction as to locality, quantity of waste, movement or volume of tide water at the point of discharge or other restriction. Laws exist and are enforced to restrict the dumping of solid refuse such as ashes and kitchen waste into the harbor, but manufacturers and municipal corporations are permitted to dispose of their drainage as they see fit. The pursuit of this custom through many years has resulted in producing many extensive nuisances, of which the Passaic river in New Jersey and Newtown and Gowanus creeks in New York are among the worst examples. The waters of these streams are highly polluted and the odors from them are exceedingly offensive. Plans have been made to sanitate the most polluted waters in the metropolitan district by carrying this sewage and other drainage to the main channels of the harbor. Extensive projects have been executed, others are being begun and some are in contemplation for carrying large quantities of sewage from areas not immediately bordering upon the harbor to the main body of the Upper harbor for disposal. One of these projects is that of the Passaic Valley Sewerage Commission, concerning which you will find information in the printed matter already referred to in this letter. Another is the project of the Bronx Valley Sewer Commission which will discharge unpurified sewage into the Hudson immediately above the boundary line of New York City. The third is the project for improving Gowanus Canal; in this case water from the Upper bay will be pumped through a channel to the head of the canal in order to flush out the polluted water into the harbor.

Persons who advocate sanitating small arms of the harbor at the expense of the water in the main channels, argue that there is an abundance of water from the rivers and ocean to dilute, diffuse and dispose of the impurities of all the municipalities in the metropolitan district for practically all time to come. In this calculation the quantity of water which enters and leaves the harbor at each tide serves as a basis upon which to compare the quantity of sewage which needs to be diluted and disposed of. It is generally believed by the public that the harbor is flushed out very much as a watercloset is flushed, by the action of the tide.

On the other hand, there are those who say that the harbor is polluted inadmissibly, that banks of mud have been formed from the solid matters carried by the sewage, that the sanitating of the tributaries of the harbor at the expense of the waters in the main channels will lead to nuisance, that practically nothing is known concerning the fate of the sewage when it is discharged into the tidal currents except that it produces an offense to the eye in the neighborhood, and that untoward consequences must follow if large additions of sewage are to be made to the polluting conditions which exist already. Those persons who are most insistent for a clean harbor advance the idea that the tidal waters oscillate back and forth in New York harbor and that there is not a flushing action that can be depended upon to carry sewage to sea in anything like a regular and reliable way. This is the main manner. It is the duty of the Metropolitan Sewerage Commission (See Chapter 639, Laws of 1906, and Chapter 422, Laws of 1908, New York State) to make a thorough investigation of the conditions of sewage disposal in the metropolitan district of New York and New Jersey and formulate a general plan or policy for keeping these waters reasonably pure. Some work has been done along this line and more will be undertaken by employees working under the immediate direction of this Commission. The Coast and Geodetic Survey is requested as a federal authority charged with the duty of investigating questions of tidal phenomena and possessing special experience in studying tidal conditions in New York harbor to supply information within its scope for the use of the Metropolitan Commission in its investigation. It is not expected that the Survey will enter deeply into biological, chemical or sanitary questions involved, although information and suggestions with regard to these topics would be welcome. What the Metropolitan Sewerage Commission desires especially is information concerning the physical phenomena of tidal currents, their volume, direction, velocity and regularity.

It is understood by the Metropolitan Sewerage Commission that the Coast and Geodetic Survey has already at hand a large amount of information concerning the currents of New York harbor, some of which data remain in the archives of the Survey and some published. The Metropolitan Sewerage Commission, representing the City and State of New York, request that a study of all existing information in the possession of and accessible to the Survey be examined and digested for the Metropolitan Sewerage Commission, having in mind the work before this Commission. On the receipt of a communication from the Survey giving the results of the Survey's study, if recommendation is made for studies in the field in order to supplement, verify or extend the information, the Metropolitan Commission will be pleased to consider any plan and estimate for that work which the Survey may propose. If in the study of existing data two or three expert assistants are needed to expedite the work, the Metropolitan Commission will be pleased to authorize the Survey to do so at the expense of this Commission. It is desirable that immediate attention be given to this matter since the results are likely materially to modify several lines of investigation which the Metropolitan Commission will undertake. The time remaining to the life of this Commission is brief.

The subjects upon which the Metropolitan Sewerage Commission request information from the Coast and Geodetic Survey may be included in the following list of questions:

1. What is the volume of water discharged through the Narrows in each direction at each tide under conditions which are (a) usual and (b) unfavorable to a large net outflow toward the sea?

2. What are the principal current phenomena, at the Narrows and at other points in the harbor, which accompany this discharge?

3. What is the volume of water discharged in each direction at each tide at controlling points in the harbor, notably the mouth of the Hudson river, the East river, the Harlem river, Kill van Kull, the Arthur Kill under conditions which are (a) usual, and (b) unfavorable to a large flow toward the sea?

4. What are the main tidal phenomena of the Passaic river, Gowanus Canal, Newton creek, Bronx river, Rahway river, Jamaica bay, Shrewsbury river and Raritan river?

5. Is there a discharge of water through the East river and New York bay from Long Island sound to the sea, and if so, how great is it under (a) usual conditions and (b) conditions which are unfavorable to the discharge of water from the harbor?

6. To what extent have changes in the depth, width and location of the channels and the construction of islands and bulkheads affected the flow of water through the harbor?

7. In general terms, what are the controlling factors which affect the flow of water in and out of New York harbor? Especially what is the effect produced by the wind?

8. Would it be feasible to establish a system of gauges in and about New York which would permit the city to make a calculation at any time of the quantities of water being carried in the main tidal currents?

9. What are the average, the maximum and minimum velocities in each direction of the currents at the principal points in New York harbor taken at the time when each current is strongest? That is, how do the velocities vary with different tides through the year.

10. What is the distance that water moves in different parts of the harbor through a complete tide, from high water to high water and from low water to low water as shown by floats, and what is the net movement of the water starting from different points toward the sea?

We shall be pleased to answer any inquiries you may make in order to make these questions explicit. We have purposely endeavored to give you considerable latitude in your replies and have prefaced this letter with a statement of our point of view in order that you may use your judgment and collect your data in the way which appears to be most likely to give us the information we desire.

Hoping you will be able to give us your full reply as soon as possible, we are,

Very sincerely,
George A. Soper,
President.

The reply of the Survey to the letter printed here as Exhibit III was dated August 14, 1908, and appears here as Exhibit IV.

EXHIBIT IV

WASHINGTON, D. C., August 14, 1908.

MR. GEORGE A. SOPER,
President, Metropolitan Sewerage Commission,
17 Battery Place, New York City.

SIR: In reply to the questions contained in your letter dated June 19, 1908, I have the honor to submit the following statements:

Before taking up the questions in their regular order, it seems best to give the fresh-water discharge or run-off for the regions considered.

Gauging stations have been maintained by the U. S. Geological Survey, in conjunction with the State Engineer and Surveyor, at Mechanicsville on the Hudson and at a point on the Mohawk river about 4 miles below Rexford Flats. The areas above these stations, and whose drainage passes by them, are shown in the below table. Now the amount of fresh water running off from areas below these gauging stations might be assumed to be related to these areas as the measured discharges are to the areas above the gauging station. Such values are given in the below table. But a closer approximation to the truth would be the values just referred to, multiplied by factors representing the ratios of the annual rainfall over the regions under consideration to the annual rainfall over the regions above the two gauging stations. These ratios have been obtained from Plate 26, Climatology of the United States, Prof. A. J. Henry, and the results after having applied the factor are also shown in the table.

The final or adopted results are the underscored values.

August 14, 1908.

TABLE CVI

NEW YORK HARBOR, N. Y.

AVERAGE DISCHARGE OF FRESH WATER IN CUBIC FEET PER SECOND

Contributing Basin	Area square miles	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Mean
Hudson and Mohawk rivers above Mechanicsville and Dunbach gauging stations..	7,940	*10,318	8,081	29,249	30,308	15,667	12,724	8,162	7,287	8,287	11,529	10,668	13,717	13,833
Hudson river (above Battery place)	13,369	**17,373 ***18,136	13,606 14,203	49,248 51,410	51,031 53,271	26,379 27,537	21,424 22,365	13,743 14,346	12,270 12,809	13,953 14,566	19,412 20,264	17,962 18,751	23,096 24,110	23,291 24,314
East river, between Governors island and Randalls island ..	36	**47 ***57	37 44	133 160	137 165	71 85	58 70	37 44	33 40	38 46	52 63	48 58	62 75	63 76
Newark bay and Kill van Kull, ignoring discharge through Arthur Kill...............	1,139	**1,480 ***1,760	1,159 1,378	4,196 4,990	4,348 5,171	2,247 2,672	1,825 2,170	1,171 1,393	1,045 1,243	1,189 1,414	1,654 1,967	1,530 1,819	1,968 2,340	1,984 2,360
.836,631,3 of above (for probable discharge through Kill van Kull, allowing for discharge through Arthur Kill)	953	**1,238 ***1,472	970 1,153	3,511 4,175	3,638 4,326	1,880 2,235	1,527 1,815	980 1,165	874 1,040	995 1,183	1,384 1,646	1,280 1,522	1,646 1,958	1,660 1,974
Upper bay (exclusive of all above-named tributaries)...	37	**48 ***58	38 46	136 165	141 171	73 89	59 72	38 46	34 41	39 47	54 66	50 61	64 78	64 78
Above the Narrows (including East river to Randalls island and all of Newark bay if no deduction were made for discharge through Arthur Kill).	1,458	**18,948 ***20,011	14,840 15,671	53,713 56,725	55,657 58,778	28,770 30,383	23,366 24,677	14,989 15,829	13,382 14,133	15,219 16,073	21,172 22,360	19,590 20,689	25,190 26,603	25,403 26,828
Above the Narrows (including East river to Randalls island and .836,631,3 of Newark bay and Kill van Kull)	14,395	**18,706 ***19,823	14,651 15,446	53,028 55,910	54,947 57,933	28,403 29,946	23,068 24,322	14,798 15,601	13,211 13,930	15,025 15,842	20,902 22,039	19,340 20,392	24,868 26,221	25,079 26,442
Arthur Kill (exclusive of Newark bay)..................	167	**217 ***264	170 207	615 748	637 775	330 401	268 326	172 209	153 186	174 212	242 294	224 272	289 351	291 354
Arthur Kill (including .163,368,7 of Newark bay and Kill van Kull)............	353	**459 ***552	359 432	1,300 1,563	1,347 1,620	697 838	566 681	363 437	324 389	368 443	512 615	474 569	611 733	615 739
Raritan river................	1,105	**1,436 ***1,669	1,125 1,307	4,071 4,731	4,218 4,902	2,181 2,534	1,771 2,058	1,136 1,320	1,014 1,178	1,153 1,340	1,604 1,864	1,485 1,726	1,909 2,219	1,925 2,237

*From gauging by U. S. Geological Survey (see Report of Coast and Geodetic Survey for 1907, page 450).

**Computed on assumption that discharge is proportional to areas drained.

***These results contain a factor to allow for difference in annual precipitation in areas compared.

TABLE CVII

NEW YORK HARBOR, NEW YORK

V. E. C.—August 15, 1908.

AVERAGE DISCHARGE OF FRESH WATER IN CUBIC FEET PER SIX LUNAR HOURS

Contributing Basin	January	February	March	April	May	June	July	August	September	October	November	December	Mean
Hudson and Mohawk rivers above Mechanicsville and Dunbach gauging stations..	230,680,000	180,667,000	653,920,000	677,596,000	350,267,000	284,470,000	182,478,000	162,915,000	185,272,000	257,754,000	238,504,000	306,671,000	309,266,000
Hudson river, New York (above Battery place)......	388,408,000 405,467,000	304,189,000 317,536,000	1,101,038,000 1,149,373,000	1,140,900,000 1,190,980,000	589,755,000 615,645,000	478,976,000 500,014,000	307,252,000 320,734,000	274,320,000 286,371,000	311,947,000 325,652,000	433,994,000 453,042,000	401,576,000 419,216,000	516,357,000 539,027,000	520,726,000 543,588,000
East river, between Governors island and Randalls island..	1,051,000 1,274,000	827,000 984,000	2,973,000 3,577,000	3,063,000 3,689,000	1,587,000 1,900,000	1,297,000 1,565,000	827,000 984,000	738,000 894,000	850,000 1,028,000	1,163,000 1,408,000	1,073,000 1,297,000	1,386,000 1,677,000	1,403,000 1,690,000
Newark bay and Kill van Kull, ignoring discharge through Arthur Kill..............	33,088,000 39,348,000	25,912,000 30,808,000	93,810,000 111,561,000	97,208,000 115,608,000	50,236,000 59,738,000	40,802,000 48,515,000	26,180,000 31,143,000	23,363,000 27,790,000	26,582,000 31,613,000	36,978,000 43,976,000	34,206,000 40,667,000	43,999,000 52,315,000	44,364,000 52,757,000
.836,631,3 of above (probable distance through Kill van Kull, allowing for discharge through Arthur Kill).......	27,682,000 32,920,000	21,679,000 25,775,000	78,484,000 93,335,000	81,327,000 96,721,000	42,029,000 49,979,000	34,136,000 40,589,000	21,903,000 26,055,000	19,546,000 23,250,000	22,239,000 26,448,000	30,937,000 36,792,000	28,618,000 34,023,000	36,811,000 43,768,000	37,116,000 44,138,000
Upper bay (exclusive of all above-named tributaries)...	1,073,000 1,297,000	850,000 1,028,000	3,041,000 3,689,000	3,152,000 3,823,000	1,632,000 1,990,000	1,319,000 1,610,000	850,000 1,028,000	760,000 917,000	872,000 1,051,000	1,207,000 1,476,000	1,118,000 1,364,000	1,431,000 1,744,000	1,442,000 1,751,000
Above the Narrows (including East river to Randalls island and all of Newark bay if no deduction were made for discharge through Arthur Kill).	423,620,000 447,386,000	331,778,000 350,356,000	1,200,862,000 1,268,200,000	1,244,323,000 1,314,100,000	643,210,000 679,273,000	522,394,000 551,704,000	335,109,000 353,889,000	299,181,000 315,972,000	340,251,000 359,344,000	473,342,000 499,902,000	437,973,000 462,544,000	563,173,000 594,763,000	567,935,000 599,786,000
Above the Narrows (including East river to Randalls island and .836,631,3 of Newark bay and Kill van Kull).........	418,214,000 440,958,000	327,545,000 345,323,000	1,185,536,000 1,249,974,000	1,228,442,000 1,295,213,000	635,003,000 669,514,000	515,728,000 543,778,000	330,832,000 348,801,000	295,364,000 311,432,000	335,908,000 354,179,000	467.301,000 492,718,000	432,385,000 455,900,000	555,985,000 586,216,000	560,687,000 591,167,000
Arthur Kill (exclusive of Newark bay).................	4,851,000 5,902,000	3,801,000 4,628,000	13,750,000 16,723,000	14,241,000 17,327,000	7,378,000 8,965,000	5,992,000 7,288,000	3,845,000 4,673,000	3,421,000 4,158,000	3,890,000 4,740,000	5,410,000 6,573,000	5,008,000 6,081,000	6,461,000 7,847,000	6,504,000 7,900,000
Arthur Kill (including .163,-368,7 of Newark bay and Kill van Kull)............	10,257,000 12,330,000	8,034,000 9,661,000	29,076,000 34,949,000	30,122,000 36,214,000	15,585,000 18,724,000	12,658,000 15,214,000	8,122,000 9,761,000	7,238,000 8,698,000	8,233,000 9,905,000	11,451,000 13,757,000	10,596,000 12,725,000	13,649,000 16,394,000	13,752,000 16,528,000
Raritan river................	32,105,000 37,314,000	25,152,000 29,221,000	91,015,000 105,771,000	94,302,000 109,594,000	48,738,000 56,653,000	39,594,000 46,011,000	25,398,000 29,511,000	22,670,000 26,337,000	25,778,000 29,958,000	35,861,000 41,673,000	33,200,000 38,588,000	42,680,000 49,610,000	43,041,000 50,002,000

Annual Rainfall: Hudson and Mohawk valleys above gauging stations 37 inches; Hudson valley below gauging stations 41 inches; East river 44½ inches; Newark bay basin 44 inches; Upper bay 45 inches; Arthur Kill basin 45 inches; and Raritan river basin 43 inches.

1. What is the volume of water discharged through the Narrows in each direction at each tide under conditions which are (a) usual and (b) unfavorable to a large net outflow toward the sea?

At Fort Wadsworth the width of the Narrows is 1 statute mile, or 5,280 feet, and the average depth at half-tide level 61 feet, thus making the area of the section 322,080 square feet. Judging from observations made near this section in 1858, 1885, and 1886, it appears that the value of the strength of the flood or ebb stream measured when the surface current is greatest is 2.0 knots per hour, or 3.378 feet per second. Now, according to rules which have been deduced in connection with various rivers, the mean or cross-sectional velocity is about 0.75 times the value of the velocity belonging to the swiftest surface thread. Cf.:

Encyclopædia Britannica, Vol. 12, pp. 509, 510.

Darcy and Bazin: Recherches Hydrauliques (Atlas), Plates 19-23.

Merriman: A Treatise on Hydraulics (4th Ed.), Art. 113.

Bovey: A Treatise on Hydraulics (2d Ed.), p. 259.

Murphy: Accuracy of Stream Measurements (Water-Supply and Irrigation Paper No. 95), p. 138.

The maximum surface velocity being 2.0 knots, the cross-sectional velocity will, according to the above rule, be 2.0×0.75 or 1.5 knots per hour=2.5335 feet per second.

The entire volume of tide water passing this section during a flood or ebb period of 6 lunar hours, or 22,357 seconds, is, since the current curve is approximately a sine curve,

$$\begin{aligned} &\frac{2}{\pi}\times 22{,}357\times 322{,}080\times 2.5335\\ &=14{,}233\times 322{,}080\times 2.5335=\\ &\qquad 4{,}584{,}164{,}640\times 2.5335=11{,}613{,}981{,}014 \end{aligned}$$

cubic feet. The above velocities are for ordinary maximum or strengths of flood or ebb. They vary during the month about as the rise or fall (range) of tide upon which they occur varies. The amount of this variation can be ascertained from the answer to question No. 7.

Mitchell's estimate based upon observations made in 1885 and given upon page 36, Coast and Geodetic Survey Report for 1886, is 13,261,755,813 cubic feet.

2. What are the principal current phenomena, at the Narrows and at other points in the harbor, which accompany this discharge?

The principal tidal current phenomena can be seen from the charts constituting Figs. No. 12 and 13, Appendix No. 6, Coast and Geodetic Survey Report for 1907. The Roman numerals denote the Greenwich lunar time of the strength of flood. The "tidal hours" given at the bottom of each page show the Greenwich lunar times of high and low waters. Consequently, the times of the maximum current can be compared directly with the times of the tide. For instance, it will be noticed (from Fig. 13) that the time of maximum flood current at the mouth of the Hudson river occurs at very nearly the time of high water at Governor's Island, whose high-water tidal hour is given as XII.73. It will also be noticed that the flood (or ebb) current in Kill van Kull is 2½ lunar hours earlier than the flood (or ebb) in the axis of the upper bay.

1 lunar hour=1.03505 solar hours.

The sharp arrows with numerals written upon them denote the direction and velocities of the flood stream, at the time of its strength or maximum velocity.

The blunt arrows denote the non-tidal surface stream which happened to be running at the time when the observations were taken. On account of the shortness of the periods of observation, no great weight should be attached to the velocities denoted by the blunt arrows. The permanent or net discharge should be taken from the table given above.

In the Hudson river the tidal currents are due chiefly to the progressive wave motion there existing. This is proved by the fact that the greatest flood and ebb velocities occur at very nearly the times of the local high and low waters. Through Kill van Kull and Arthur Kill the tidal currents are nearly hydraulic; *i. e.,* they flow from the body having temporarily the higher surface level to the one having temporarily the lower. The flow is caused by a difference in head which temporarily exists between the bodies connected. The same is true of the currents through East river, and is probably true for those through the Harlem.

The distance over which any floating particle will be carried by the tide can be estimated from Figs. 12 and 13, referred to above. These charts show the currents at the time of strength. At any other time they may be inferred from those given. Suppose at a given place the strength of the tidal current is A. At any other time the velocity will be $A \cos 30\, t$ where t denotes the number of lunar hours after the time of strength. If solar hours are used then the velocity will be $A \cos$ *29.98 t. By computing and plotting a number of these velocities at each of several stations in the locality concerned it is possible to make an estimate of how a floating particle will be drifted by the currents.

In a channel where the current does not vary much from point to point in the direction of the motion, a particle having a velocity of A knots per (solar) hour will not be driven from its mean position by a distance $A \times$ length of ¼ tidal period or $A \times 3.10515$ but, because of the harmonic or sine like character of the motion, the distance from the mean position will be

$$\frac{2}{\pi} A \times 3.10515 \text{ knots}$$

or about two-thirds of the distance which would be covered were the maximum or strength velocity maintained throughout the quarter tidal period.

(Corrections. On the chart (Fig. 13) the station between Governors Island and Bedloe Island should be moved a short distance westward so as to conform to the position given on p. 387, Coast and Geodetic Survey Report for 1907. On p. 385 same Report, the strength of the ebb stream for the station off 23d street, East river, should read 2.62 instead of 1.72. The arrows upon Fig. 13 should be altered in accordance with this correction.)

The strong currents through the Narrows and the fact that the strength of flood or ebb occurs considerably earlier than the time of high or low water indicates that they are largely hydraulic; *i. e.,* due to a difference in head between the waters of the upper bay and the waters outside. There is, however, considerable progressive wave motion accompanying this hydraulic motion.

The answers to most of the other questions have a bearing upon the answer to this one.

3. What is the volume of water discharged in each direction at each tide at controlling points in the harbor, notably the mouth of the Hudson river, the East

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*This should be 28.98—K. A.

river, the Harlem river, Kill van Kull, the Arthur Kill, under conditions which are (a) usual, and (b) unfavorable to a large flow toward the sea?

Between Battery Place and Communipaw Ferry the width of the river is 4,500 feet and the average depth at half-tide level is 40 feet; the area of the section is therefore 180,000 square feet. Judging from current observations made near this section in 1854, 1855, 1858, 1872, 1873, it appears that the velocity of the tidal current at the time of their strength, or ordinary maximum, is 1.9 knots for the portion of the stream having the greatest surface velocity. According to the rule mentioned in the answer to No. 1, the average velocity of the cross section is about 0.75 of 1.9 knots= 1.425 knots per hour = 2.4068 feet per second.

The entire volume of tide water passing this section during a flood or ebb period of 6 lunar hours, or 22,357 ordinary seconds, is,

$$14{,}233 \times 180{,}000 \times 2.4068$$
$$= 6{,}166{,}077{,}192 \text{ cubic feet.}$$
$$14{,}233 = \frac{2}{\pi} \times 22{,}357.$$

Mitchell's estimate based upon observations made in 1858 and 1872, given upon page 118, U. S. Coast Survey Report for 1871, is 4,511,000,000 cubic feet; while his latest estimate, given upon page 36, Report for 1886, is, for a section off 39th street, 6,611,331,779.

At Green street, Greenpoint, Brooklyn, the width of East river is 3,000 feet, while the half-tide level average depth is 32 feet. The area of the section is, therefore, 96,000 square feet. Current observations made near this section in 1854, 1858, 1873, 1885 and 1886 indicate a maximum surface velocity of 2.4 knots. Upon the assumption used in connection with the Narrows and the Hudson river the cross-sectional velocity will be 1.8 knots, or 3.0402 feet per second. This velocity gives as the tidal volume passing this cross-section

$$14{,}233 \times 96{,}000 \times 3.0402 = 4{,}154{,}031{,}994 \text{ cubic feet.}$$

The value of this tidal volume, as given upon page 118 of the Coast Survey Report for 1871, is 4,383,000,000 (ebb), and upon page 36 of the Coast and Geodetic Survey Report for 1886 is 4,231,056,466 cubic feet.

Off 81st street the width of the west channel is 800 feet, the average half-tide depth is 39 feet and so the area of the section is 31,200 square feet. Similar numbers for the east channel, a little southward from Graham avenue, are 600, 26½ and 15,900 respectively.

In the former section the maximum surface velocity is 4.9 knots and in the latter 4.0 knots, according to observations made in 1857 and 1874. The cross-sectional velocity for the west channel at the time of strength will, according to the rule already used, be 3.675 knots per hour= 6.2069 feet per second. For the east channel it will be 3 knots per hour=5.0670 feet per second.

The volume passing the western section in 6 lunar hours is

$14{,}233 \times 31{,}200 \times 6.2069 = 2{,}756{,}295{,}600$ cubic feet, and that passing the eastern

$14{,}233 \times 15{,}900 \times 5.067 = 1{,}146{,}685{,}915$ cubic feet.

The sum of these two volumes is 3,902,981,515 cubic feet.

This Survey has made no current observations in the Harlem river proper.

A section near the mouth of Kill van Kull, between Constable Point and New Brighton, measures, at mean water stage, 1,425 feet in width and 27 feet in depth, the area of the section therefore being 38,475 square feet.

Current observations made in 1856 and 1885 indicate a maximum surface velocity for this section of 2.3 knots at the time of ordinary strength. Applying the same rule at that used for the Hudson river the velocity for the cross-section at the time of strength would be 1.725 knots or $1.725 \times 1.689 = 2.9135$ feet per second. This velocity gives as the tidal volume passing this cross section

$$14{,}233 \times 38{,}475 \times 2.9135 = 1{,}595{,}475{,}341 \text{ cubic feet.}$$

The theoretical velocity for a section extending across Kill van Kull is

$$\frac{\text{Area Newark bay and branches at H. T. L.}}{\text{Area cross section at Half Tide level}} \times \text{rate of rise and fall of surface of the bay.}$$

The level of the bay and nearby branches rises and falls about 4.5 feet. The interval of time between high and low water is approximately 6 lunar hours, or 22,357 ordinary seconds. Since rise and fall is approximately harmonic, or sine like, the velocity of the current at the time of strength will be $\frac{\pi}{2}$ $(=1.5707963)$ times the average velocity $\frac{\pi}{2} \div 22{,}357 = 0.00007025971$.

The area of the waters above this section, including most of the Kill van Kull, Newark bay, the Passaic river as far as the Falls, and the Hackensack river and branches, measures 15.3 square statute miles, or 426,539,520 square feet. The cross-sectional velocity at the time of strength would be, if Arthur Kill were cut off from Newark bay by a dam at Elizabethport,

$$\frac{426{,}539{,}520}{38{,}475} \times 0.00007025971 \times 4.5 = 3.505093 \text{ feet}$$

per second. The tidal volume is $426{,}539{,}520 \times 4.5 = 1{,}919{,}427{,}840$ cubic feet, the most of which passes through Kill van Kull.

According to the estimate made upon page 36, Coast and Geodetic Survey Report for 1886, the tidal volume passing the Kill van Kull at West New Brighton is 1,751,259,867 cubic feet.

A few observations made in the Arthur Kill off Elizabethport, just above the mouth of the Elizabeth river, in 1856 and 1885, indicate a maximum surface velocity of 1.8 knots or 18/23 the value observed in Kill van Kull. The section of Arthur Kill is about $600 \times 16 = 9{,}600$ square feet, which would be equivalent to 18/23 of 9,600, or *7854.5 square feet if the velocity were 2.3 knots instead of 1.8 knots. Hence the computed velocity in Kill van Kull should be reduced by the ratio

$$\frac{38{,}475}{38{,}475 + 7{,}513} = 0.8366313.$$

3.505093 multiplied by this number gives 2.9324705 as the theoretical cross-sectional velocity of Kill van Kull. The computed tidal volume multiplied by the same number gives 1,605,853,409 for the corrected theoretical amount entering and leaving Kill van Kull.

This agrees well with the results from determination first given.

Of the waters entering and leaving Newark bay and tributaries, about 84 per cent. passes Kill van Kull and 16 per cent. passes the upper end of Arthur Kill.

Final check. Reckoned in billions of cubic feet, the tidal flow during a complete flood or ebb of 6 lunar hours is as follows:

The Narrows	(Fort Wadsworth)	11.61
The Hudson	(Battery place)	6.17
East river	(Green street)	4.15
Kill van Kull	(Near East end)	1.60

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*Should be 7513—see Letter of Perkins to Allen, Sept. 30, 1908. The correct value has been used in computation. Change made here by G. A. S.

From Fig. 13, referred to above, the current hours for water flowing towards the Upper bay are as follows:

	Hour	Equivalent in Degrees
The Narrows	XI.6	348
The Hudson	VI.8 (= XII.8 — 6)	204
East river	V.3 (= XI.3 — 6)	159
Kill van Kull	III.8 (= IX.8 — 6)	114

Now it is known with a good degree of accuracy that the semi-daily tidal wave attains its maximum height in the upper bay XII.84 o'clock, and so the time of half-tide level (rising) will be XII.84—3=IX.84=295°. Evidently the rate influx into the harbor should be greatest at the time of half-tide level rising. The rate influx at any time t is proportional to

$$11.61 \cos (30\,t-348)+6.17 \cos (30\,t-204).$$
$$+4.15 \cos (30\,t-159)+1.60 \cos (30\,t-114).$$

If t denote the time of maximum influx (=IX.84), the following relation should obtain:

$$11.61 \sin (295^\circ-348)+6.17 \sin (295-204)$$
$$+4.15 \sin (295-159)+1.60 \sin (295-114)=0.$$

The sum of the positive terms comes out 9.05 and of the negative terms —9.30, or within 2 or 3 per cent. of exact agreement. The amount of the influx for a tide is

$$11.61 \cos (295-348)+6.17 \cos (295-204)$$
$$+4.15 \cos (295-159)+1.60 \cos (295-114).$$

This comes out as 2.29. Now the area of the Upper bay between the sections just mentioned is 22 square statute miles=613,324,800 square feet. This multiplied by the range of tide, 4.4 feet, gives 2.6986 billions of cubic feet as the tidal volume. This does not agree with the above value, 2.29, very closely, but being a quantity depending upon the excess of the water flowing through the Narrows over the water flowing out through the three other openings, its value is very sensitive varying greatly for small variations of the assumed data.

The foregoing estimates of the fresh water discharge, and the volumes of tide water passing the given cross sections, have been made by methods quite different from those used by Professor Mitchell, and there is a general agreement between the results just obtained and those obtained by him. In the present instance, care has been taken to reduce observed current velocities to their mean or ordinary condition, *i.e.,* to correct for the fact that the ranges of tide upon the days when current observations were taken generally differed from their mean values. Wherever it has been found necessary to resort to empirical rules, it has been so stated and these have been made as few and as simple as seemed possible.

One of the chief uncertainties connected with the measurements has been the widths of the channels where piers or wharves project into them. These certainly change the character of the flow along the shore and the amount will depend upon the openness of their substructures.

If the present estimates are deemed inadequate for the purpose of the Commission, it would seem that the only way to obtain improved values would be to gauge more extensively with a meter each of the given cross-sections. The gauging should be made at regular intervals of distance from one end of the cross-section and at regular height intervals. This should be continued day and night for two or four weeks. Each section would require as many observing parties as there are, say, hundred-foot intervals across the stream.

4. What are the main tidal phenomena of the Passaic river, Gowanus Canal, Newtown creek, Bronx river, Rahway river, Jamaica bay, Shrewsbury river and Raritan river?

The Passaic river, Newtown creek, Bronx river, Rahway river and Raritan river, are imperfect examples of tidal rivers with estuaries. In such streams there is a tendency for the maximum flood velocity to occur less than three hours before the time of local high water and the maximum ebb velocity to occur less than three hours before the time of local low water. In a very long tidal river, the strength of flood or ebb would occur almost as late as the time of local high or low water. In streams of the kind here considered, the range of tide may increase somewhat in going up stream provided the cross-section diminished gradually. If, however, piers or bridges interfere seriously with the flow of tide the range above such obstructions will be decreased, and as a consequence the tidal volume entering a river so obstructed will be diminished. Suitable dredging will increase the range of tide.

The range of tide at Passaic Light, Newark bay, is 4.7 feet; at Newark it is 5.0 feet and at Passaic about 3 feet.

The range of tide at Sandy Hook is 4.7 feet; Keyport, Raritan bay is 5.3 feet; at South Amboy, Raritan river, 5.3 feet; at New Brunswick 6.0 feet. The range of tide at the mouth of the Rahway river is 5.0 feet; at the mouth of Newtown Creek 4.0 feet; and at the mouth of the Bronx river 7.1 feet.

Jamaica bay is a tidal reservoir connected with the ocean by Rockaway inlet. The tidal currents through this inlet are hydraulic, the greatest velocity occurring when the bay is being filled or emptied most rapidly, or about three hours before high or low water in Jamaica bay. The considerable tidal area of the bay necessitates rather strong currents through the inlet, and the erosion due to these produce a depth as great as 50 feet just west of Rockaway Beach.

The theoretical velocity for a section extending from Barren Island to the northern coast of Rockaway Beach is,

$$\frac{\text{Area of bay above cross-section at H. T. L. stage}}{\text{Area of cross-section at half-tide level stage}} \times \left\{ \begin{array}{l} \text{rate of rise and fall} \\ \text{of surface of the bay.} \end{array} \right.$$

Suppose the level of the bay as a whole rises and falls 4 feet. The interval of time between high and low water is approximately 6 lunar hours, or 22,357 ordinary seconds. Therefore the average rate of rise or fall per second is $4 \div 22{,}357$ foot. The tide curve being approximately a sine curve, the maximum rate will be the average rate multiplied by $\frac{\pi}{2}$ or 1.5708.

The area of Jamaica bay and tidal tributaries is 19.275 square statute miles (=537,356,160 square feet), at mean sea level. The cross-section from Barren Island to the northern shore of Rockaway Beach is, at the time of mean sea level, 79,425 square feet, the width being 3,177 feet and the average depth 25 feet.

$$\therefore \frac{537{,}356{,}160}{79{,}425} \times \frac{4}{22{,}357} \times 1.5708$$

=1.9014 feet per second, or 1.1258 knots per hour, for the cross-sectional velocity at the time of the strength of flood or ebb. In the center of the channel the velocity will be greater than this, while along the shores it will be less.

A few observations made in 1877 near this cross-section give a surface velocity at the center of stream.

Strength of flood, 1.9 knots.
Strength of ebb, 2.4 knots.

Shrewsbury river communicates with the waters inside of Sandy Hook through a narrow passageway. As a result the range of tide in the broad portion of the river is considerably smaller than the range around Sandy Hook, and the time of tide is considerably later. A deepening of the passageway would cause a greater rise and fall of the water in the broad portion of the river and so increase the tidal volume entering and leaving the river. It would also accelerate the time of the occurrence of the tide. The flow through the passageway is nearly hydraulic; *i. e.,* the water flows towards the inner or outer body according to which is for the time being the lower.

Gowanus Channel is so situated that the tidal flow must be very small. The volume of water which enters upon a flood tide or leaves upon an ebb tide will be the area of this canal multiplied by the range of tide which is practically the same as the range at Governor's Island. The length of the canal (and its branches) above Hamilton avenue is 8,250 feet. This implies a cross-sectional velocity of $\frac{2.55^{*}}{\text{depth at half-tide level}}$ feet per second at the time of strength of flood or ebb. For a depth of 10[†] feet this would be 0.255 foot per second, and for a depth of 5 feet, 0.510 foot per second. Near the head of the canal, or of any branch of the canal, the velocity from the tide is practically zero. The above computation relates to a cross-section of ordinary size at or near Hamilton avenue.

5. Is there a discharge of water through the East river and New York bay from Long Island sound to the sea, and if so, how great is it under (a) usual conditions and (b) conditions which are unfavorable to the discharge of water from the harbor?

There is doubtless a small resultant flow through East river from Long Island sound into Upper New York bay, although observations do not conclusively show it. As already stated the flow through East river is chiefly hydraulic, the water flowing always toward that body which is the lower for the time being.

Now the greatest velocity possible in an open channel will be found where the cross-section has the least area. In case of the East river this section extends between Astoria and Ward's Island. The greatest possible velocity will be

$$v = \sqrt{2g\ (\zeta_{,} - \zeta_{,,})} \tag{1}$$

where $\zeta_{,}$, $\zeta_{,,}$ denote the heights of the surface of the two bodies above half-tide level. If the channel have a sensible length, say more than a few hundred feet, the velocity at the region where it is greatest will be given by the formula

$$v^2 = \frac{2g\ (\zeta_{,} - \zeta_{,,})}{1 + \zeta' \frac{P}{\Omega}\, l} \tag{2}$$

where ζ' is an empirical abstract number equal to about 0.007565, P the wetted perimeter, Ω the area of the cross section, l the length of the channel. If the channel

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[*] $V = \frac{\text{Tidal prism}}{\text{Area} \times \text{duration}}$ = mean velocity at outer end.

Tidal prism = length × width × range of tide.
Area = width × depth.

$V = \frac{\text{Length} \times \text{range}}{\text{Depth} \times \text{duration}}$. Duration = 6 lunar hours = 22357 seconds.

$$\text{Max. } V = \frac{\pi}{2}\left(\frac{\text{Length} \times \text{range}}{\text{Half-tide depth}}\right) = \frac{\frac{\pi}{2} \times 8250 \times 4.4}{22357 \times \text{depth}} = \frac{2.55}{\text{Half-tide depth.}}$$

[†] This depth is used for purposes of illustration, the correct depth not being known.

have a gradually varying cross-section, the velocity at the region where it is greatest will be v where

$$ {}^{*}v^2 = \frac{2g\ (\zeta_{,}-\zeta_{,,})}{1+\zeta'\ \frac{P_1}{\Omega_1} l_1 + \zeta_1\ \frac{P}{\Omega_2} 2\, l_2 \left(\frac{\Omega_1}{\Omega_2}\right)^2 + \ldots\ldots} \tag{3} $$

Here the subscript $_1$ is supposed to refer to the portion of the channel where the smallest cross-section, and so the greatest velocity, occurs. The subscripts $_2$, $_3$, ... refer to other portions of the channel.

The mean range of tide at Willets Point is 7.2 feet; the tidal hour of the semi-daily wave is III.9. The corresponding quantities for Governor's Island are 4.4 and XII.8. By combining two sine curves (Coast and Geodetic Survey Report for 1907, pp. 328, 542), these values give X.9 as the time of the greatest eastward downward slope throughout East river, and 4.3 feet as the difference in head at this time. The time of the greatest slope in the opposite direction is X.9—6=IV.9. These times agree approximately with the times of the strength of flood and ebb throughout the greater portion of East river, observation making the latter XI.3 and V.3.

The formula

$$ v = \sqrt{2\ g\ (\zeta_{,} - \zeta_{,,})} $$

becomes

$$ v = 8.0215\sqrt{\zeta_{,}-\zeta_{,,}} = 8.0215\sqrt{4.3} = 8.0215\times 2.0736 = 16.63 $$

feet per second, a value much in excess of the measured value. This shows that the resistance factor in the denominator of the more general expression for v^2 is several times unity.

If the East river were very much deeper and broader than it now is in all portions of its course except in the Hell Gate, then the quantity of water passing through Hell Gate during a flood or ebb period of 6 lunar hours would depend upon the area of the flood or ebb cross-section. The rate of the flood and ebb streams at the times of their maximum values being, upon the above hypothesis, sensibly the same, the rate of discharge in the two directions at these times will be proportional to the flood and ebb sections. In the Hell Gate as it exists the area of the section for the east-going stream averages less than the area of the section for the west-going stream.

The high water tidal hour between Astoria and Ward's Island is about III.5. The time of attaining the following half-tide level will be III.5+3=VI.5. This shows that when the west-going stream (ebb) has its maximum value (viz., at V.3) the water in the Hell Gate is falling but lacks 1.2 lunar hours (VI.5—V.3) of reaching its half-tide level stage. The range of tide here being 5.6 feet, the surface will then be 2.8 sine (1.2×30)=2.8 sine 36°=1.646 feet above its half-tide level. These results are in general accord with those shown in Diagram C, page 416, Coast and Geodetic Survey Report for 1886. If the half-tide depth in this locality were 35 feet, it might be inferred that the rate of westward discharge at the time of strength of current would be to the rate of eastward as 35+1.646:35—1.646, or about 1.1. Considering a whole flood or ebb this ratio would be not far from 1.05. But an increase in the cross-section of the Hell Gate does not involve a proportional increase

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*Correctly written

$$ V^2 = \frac{2\,g\,(\zeta_{,} - \zeta_{,,})}{1 + \zeta'\frac{P_1}{\Omega_1}\ l_1\ + \zeta'\ \frac{P_2}{\Omega_2} l_2\ \left(\frac{\Omega_1}{\Omega_2}\right)^2 \ldots.} \tag{3} $$

in the quantity of water transmitted. For, as noted above, the resistance factor, in the denominator of (3), due to the friction in the river bed is responsible for the diminution of the velocity from its theoretical value

$$\sqrt{2\,g\,(\zeta_{\prime}-\zeta_{\prime\prime})}$$

to its observed value. This factor increases or decreases if the size of the cross-section at the Hell Gate (Ω_1) increases or decreases, Ω_2, Ω_3, etc., remaining the same. Because this factor greatly exceeds unity it seems probable that the volume transmitted westerly can be not more than 1 or 2 per cent. greater than the volume transmitted easterly. It almost certainly plays no important part in flushing out New York harbor.

6. To what extent have changes in the depth, width and location of the channels and the construction of islands and bulkheads affected the flow of water through the harbor?

Owing to the fact that the tidal areas such as the Upper bay, Hudson river, and Newark bay are large in comparison with any reclaimed areas, it follows that the flow in or out of the harbor can scarcely be sensibly affected because of the tidal area already lost. Of course a sufficient extension of the piers into the Hudson river would reduce the amount of tide water passing up and down that river. However, neither the reclamation of shoal areas nor the extension of the piers into the Hudson seems, up to the present time, to have sensibly interfered with the tide. For instance, the mean range of tide at Dobbs Ferry, determined from observations made in the years 1856, 1858, 1885, 1886 and 1900, has the values 3.71, 3.69, 3.58, 3.60 and 3.66 feet, respectively.

The dredging of the channels in the Lower bay has probably produced no sensible alteration in the general circulation of the harbor.

7. In general terms, what are the controlling factors which affect the flow of water in and out of New York harbor? Especially what is the effect produced by the wind?

The variability of the drainage discharge from month to month has been considered in answer to question No. 1.

The variability of the quantity of other water entering or leaving the harbor may be either regular, that is, dependent upon the known or predictable variation in the rise and fall of the tide; or it may be irregular, that is, dependent upon the effects of the wind.

The mean range of tide at Governor's Island is 4.4 feet, the spring range 5.3 feet and the neap range 3.4 feet. The spring tides occur about 25.6 hours after new moon or full moon and neap tides as many hours after the first or third quarter of the moon. The perigean range of the tide is 5.3 feet and occurs about 37.8 hours after the moon is in perigee; the apogean range is 3.8 feet and occurs 37.8 hours after the moon is in apogee. At the time of the moon's extreme fortnightly declination north or south from the celestial equator, the difference in height between two consecutive high waters is 1.0 foot and between two consecutive low waters 0.3 foot.

The above figures indicate the average value of the principal variations in the tide at Governor's Island.

Of course, if the new or full moon happens to occur on the day when the moon is in perigee, the ranges of tide of that day will exceed the ordinary value of spring ranges by a quantity about equal to the excess of the perigean range above the mean range.

The ordinary extreme value of the annual fluctuation of the surface of the Upper bay due to the winds is about 4 feet. On one or more days of each winter it is usual for the winds to produce an extreme depression in the water's surface of about 2 feet below the regular tidal, or predictable, height, that it, below the surface as influenced by the tides alone. Some time during each year the winds ordinarily produce an extreme elevation in the surface of about 2 feet above the regular tidal, or predictable, height.

8. Would it be feasible to establish a system of gauges in and about New York which would permit the city to make a calculation at any time of the quantities of water being carried in the main tidal currents?

It might be well to establish and maintain a gauge upon the Hudson river somewhere above Manhattan Island, say, at Dobbs Ferry or at some point a few miles further north. If the range of tide were there found to diminish from year to year it would indicate that the tidal movements were being reduced because of the incroachment of the piers and bulkheads from the New York and New Jersey sides of the river. For similar reasons gauges might be maintained, one on Newark bay, say at Passaic Light, one on the Passaic river near Paterson, and one on the Hackensack river near Hackensack.

9. What is the average, the maximum and minimum velocities in each direction of the currents at the principal points in New York harbor taken at the time when each current is strongest? That is, how do the velocities vary with different tides through the year?

Answer included under answers to Nos. 1 to 4 and No. 7.

10. What is the distance that water moves in different parts of the harbor through a complete tide, from high water to high water and from low water to low water as shown by floats, and what is the net movement of the water, starting from different points, towards the sea?

The rate of movement of the water towards the sea (due to fresh water above the point considered) can be ascertained by dividing the fresh water discharge per second or per 6 lunar hours by the area cross-section through the given point. For instance, through the Narrows the average cross-sectional velocity of the discharge is 26,442÷322,080=0.0821 foot per second. It is least in August and greatest in April.

Between Battery Place and Communipaw Ferry the cross-sectional velocity of discharge is 24,314÷180,000=0.1351 foot per second on an average throughout the year.

The distance through which the water moves in a given time or through a complete tide can be ascertained as explained in the answer to No. 2.

Free floats have been used in a few cases. A blue print* showing the courses of the floats in East river together with an explanatory table is given below.

The copy of the first Report of the New York Bay Pollution Commission is returned, as requested.

Respectfully yours,
F. W. Perkins,
Act'g Superintendent.
A. B.

1 enclosure.

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*Not reproduced.

TABLE CVIII

Observations of Currents with Free Floats in 1874

V. E. C., August 4, 1908.

Channel West of Blackwell's Island, East River, New York

Float No.	Kind	Float dropped		Float picked up		Distance	Current		Observed tide at Governor's Island
		Time	Place	Time	Place		Kind	Computed time, maximum	
						Feet			
1	18-foot pole	July 30 1.50 P. M.	300 feet off New York shore, just above Section 17	July 30 2.00 P. M.	Just below Section 15	4,280	Ebb	1.48 P. M.	H. W. 8.09 A. M. L. W. 3.30 P. M.
2	" "	2.25 P. M.	500 feet off New York, just above Section 17	2.35 P. M.	Just below Section 15	3,900	"		
3	" "	July 31 7.51 A. M.	100 feet off New York, just below Section 14	* 8.19 A. M.	100 feet off New York, just above Section 17	4,870	Flood	8.25 A. M.	H. W. 9.54 A. M. L. W. 3.55 P. M.
4	" "	9.11 A. M.	300 feet off New York, just below Section 14	9.26 A. M.	At angle 16, just above Section 17, about 100 feet off shore	4,660	"		
5	" "	10.05 A. M.	500 feet off New York, just below Section 14	10.27 A. M.	Just above Section 17, about 200 feet off New York shore	5,900	"		
6	Surface can meter	August 1 8.28 A. M.	Just below Section 14, 50 feet off reef on island side	8.46 A. M.	Angle 19	4,840	"	9.05 A. M.	H. W. 10.34 A. M. L. W. 5.09 P. M.
7	18-foot pole	9.16 A. M.	Just below Section 14, 300 feet off reef on Blackwell's island side	9.32 A. M.	Angle 17, just above Section 17, 200 feet from New York shore	4,870	"		
8	" "	10.00 A. M.	50 feet from smallpox wharf, New York	10.16 A. M.	Angle 17, above Section 17	4,030	"		
9	" "	2.07 P. M.	Just above Section 17, about 50 feet from New York shore	2.25 P. M.	Angle 19, about 300 feet, from New York shore, Section 14.	5,140	Ebb	3.27 P. M.	
10	" "	3.18 P. M.	About 200 feet off Blackwell's island side, just above Section 17	3.34 P. M.	Angle 17, just above Section 14.	4,330	"		
11	" "	August 3 9.52 A. M.	Just below Section 17, about 50 feet from New York side.	10.18 P. M.	Angle 25, just above Section 20, about 50 feet from New York side	5,290	Flood	10.45 A. M.	H. W. 12.14 P. M. L. W. 6.54 P. M

*To allow for delay caused by float No. 3 being caught between barges, 7 minutes should be deducted from time.

TABLE CVIII—Continued

OBSERVATIONS OF CURRENTS WITH FREE FLOATS IN 1874

CHANNEL WEST OF BLACKWELL'S ISLAND, EAST RIVER, NEW YORK

V. E. C., August 4, 1908.

Float No.	Kind	Float dropped		Float picked up		Distance	Current		Observed tide at Governor's Island
		Time	Place	Time	Place		Kind	Computed time, maximum	
						Feet			
12	18-foot pole..........	August 3 10.49 A. M.	Just below Section 17, about 250 feet from New York.....	11.02 P. M.	Angle 14, opposite Baxter's bath house, about 150 feet off.....	5,590	Flood		
13	" "	11.32 A. M.	Just below Section 17, about middle channel............	11.45 P. M.	Above Section 20, at angle 14..	5,530	"		
14	" "	4.02 P. M.	Just above Section 20, about 100 feet from New York side......................	4.18 P. M.	Just below Section 17, about 250 feet from New York side, angle 17..................	5,440	Ebb	5.12 P. M.	
15	" "	4.54 P. M.	Just above Section 20, about 250 feet from New York side	5.07 P. M.	At angle 14, below Section 17..	5,710	"		
16	" "	5.38 P. M.	Above Section 20, about middle of channel................	** 6.10 P. M.	At Section 17, angle 16........	6,350	"		
17	" "	August 4 11.04 A. M.	About 200 feet off Blackwell's island shore, just below Section 17..................	11.17 A. M.	At angle 15, just above Section 20..................	5,240	Flood	11.30 A. M.	H. W. 12.59 P. M. L. W. 7.49 P. M.
18	12-foot pole..........	12.12 P. M.	About 75 feet from Blackwell's island shore, just below Section 17..................	12.22 P. M.	Toward New York side, at angle 11e......................	2,040	"		
18	18-foot pole..........	12.31 P. M.	At angle 12.................	12.46 P. M.	At angle 27, 50 feet off Blackwell's island...............	3,300	"		
19	" "	4.32 P. M.	250 feet off Blackwell's island, just below Section 20.......	4.46 P. M.	About 250 feet from Blackwell's island, below Section 17.....	5,590	Ebb	6.07 P. M.	
20	12-foot pole..........	5.09 P. M.	Just below Section 20, about 100 feet off Blackwell's island	5.42 P. M.	Angle 32, about 75 feet off Blackwell's island..........	——	"		

**To allow for delay caused by float No. 16 being taken up in its course, 18 minutes should be deducted.

TABLE CIX

OBSERVATIONS OF CURRENTS WITH FREE FLOATS IN 1874

V. E. C., August 4, 1908.

CHANNEL EAST OF BLACKWELL'S ISLAND, EAST RIVER, NEW YORK

Float No.	Kind	Float dropped		Float picked up		Distance	Current		Observed tide at Governor's Island
		Time	Place	Time	Place	Feet	Kind	Computed time, maximum	
1	18-foot pole	August 4 10.51 A. M.	Just off Section 14, about 100 feet	11.12 A. M.	At angle 22, above Section 17, about 125 feet from shore	4,200	Flood	11.30 A. M.	H. W. 12.59 P. M. L. W. 7.49 P. M.
2	" "	11.39 A. M.	Section 14, about 200 feet from Blackwell's island	11.59 A. M.	Angle 21, above Section 17, about 200 feet from shore	4,690	"		
3	" "	12.27 P. M.	Below Section 14, about middle of channel	12.51 P. M.	Above Section 17, about 300 feet from shore at angle 25	4,690	"		
4	" "	4.14 P. M.	Just above Section 17, about 50 feet from Blackwell's island	4.33 P. M.	Angle 20, off Section 14, near middle of channel	4,630	Ebb	6.07 P. M.	
5	" "	5.01 P. M.	Section 17, about 200 feet from Blackwell's island shore	5.18 P. M.	Angle 18, on Section 14, about 300 feet from Long Island side	4,510	"		
6	" "	5.38 P. M.	Above Section 17, about middle of channel	5.59 P. M.	Angle 22, on Section 17, about 250 feet from Long Island shore	4,540	"		
7	12-foot pole	August 5 11.34 A. M.	Just below Section 14, about 200 feet from Long Island shore	12.20 P. M.	Section 20, at angle 47	9,720	Flood	12.35 P. M.	H. W. 2.04 P. M. L. W. 8.49 P. M.
8	Surface can meter	12.58 P. M.	Above Section 14, at Empire oil wharf	2.10 P. M.	At No. 62 on Section 20	——	"		
9	18-foot pole	11.42 P. M.	About 75 feet off Blackwell's island, just below Section 17	12.01 P. M.	About 200 feet off Blackwell's island, just above Section 20	5,170	"		
10	" "	12.24 P. M.	About 250 feet from Blackwell's island, just below Section 17	12.39 P. M.	About 350 feet off Blackwell's island, just above Section 20	5,470	"		
11	" "	1.02 P. M.	About 500 feet off Blackwell's island, just below Section 17	1.17 P. M.	Angle 19, just above Section 20, about 500 feet off Blackwell's island	5,700	"		
12	" "	4.42 P. M.	Just above Section 20, about 200 feet off shore	5.11 P. M.	Just below Section 17, about 100 feet off Blackwell's island	5,650	Ebb	7.07 P. M.	

TABLE CIX—Continued

OBSERVATIONS OF CURRENTS WITH FREE FLOATS IN 1874

V. E. C., August 4, 1908.

CHANNEL EAST OF BLACKWELL'S ISLAND, EAST RIVER, NEW YORK

Float No.	Kind	Float dropped		Float picked up		Distance	Current		Observed tide at Governor's Island
		Time	Place	Time	Place		Kind	Computed time, maximum	
		August 5				Feet			
13	18-foot pole..........	5.35 P. M.	About 300 feet off Blackwell's island, just above Section 20.	5.52 P. M.	At Section 18, 200 feet off Blackwell's island, just above Section 20..................	5,440	Ebb		
13½	" "	6.51 P. M.	About 400 feet from Blackwell's island....................	6.56 P. M.	About 300 feet from Blackwell's island....................	1,980	"		
14	" "	6.18 P. M.	About 600 feet off Blackwell's island, just above Section 20.	6.34 P. M.	Just below Section 17, about 350 feet from Blackwell's island..	5,560	"		
15	Surface can meter......	4.36 P. M.	Above Section 20............	5.40 P. M.	At No. 47, about 100 feet from shore, opposite Penitentiary..	8,030	"		
16	12-foot pole..........	6.19 P. M.	Above Section 20............	6.54 P. M.	At No. 34, Section 14, about 200 feet from Long Island shore.	9,450	"	7.07 P. M.	
17	" "	August 7 7.03 A. M.	25 feet North of extreme end of Blackwell's island..........	7.15 A. M.	About 200 feet off shore, below Section 19................	2,400	"	8.13 A. M.	L. W. 9.55 A. M. H. W. 3.38 P. M.
18	" "	7.28 A. M.	200 feet east of extreme end of Blackwell's island..........	7.40 A. M.	About 50 feet off Blackwell's island....................	1,890	"		
19	18-foot pole..........	7.49 A. M.	150 feet north of extreme point of Blackwell's island........	7.59 A. M.	About 200 feet off Blackwell's island....................	2,400	"		
20	" "	8.12 A. M.	300 feet north of point of Blackwell's island..............	8.24 A. M.	400 feet off Blackwell's island..	2,380	"		
21	" "	8.35 A. M.	About 400 feet off shore of Blackwell's island..........	8.51 A. M.	About 300 feet off shore of Blackwell's island..........	2,620	"		
22	12-foot pole..........	7.04 A. M.	At angle 1, about 50 feet from shore....................	7.31 A. M.	At angle No. 26............	2,190	"		
23	" "	7.44 A. M.	At angle 1..................	8.13 A. M.	About 75 feet from Blackwell's island....................	2,650	"		
24	Surface can meter......	8.25 A. M.	About 75 feet off steam boat wharf in Astoria...........	8.41 A. M.	At angle 19.................	700	"		
25	" "	8.46 A. M.	Angle 1.....................	8.59 A. M.	At No. 12, about half way between Sections 18 and 19....	1,540	"		
26	12-foot pole..........	1.21 P. M.	Angle 1, below Section 19......	2.09 P. M.	At angle 49.................	——	Flood	2.09 P. M.	
27	" "	1.20 P. M.	50 feet off shore.............	1.47 P. M.	——	——	"		

The letter consists largely of a mathematical and theoretical discussion of the flow of water, and is based largely upon the methods of studying the flow of large streams of water which engineers and physicists customarily employ where gaugings and current observations are not available.

One of the results of the study was to revise the Survey's former estimates of the flow of water in the Lower East river so that instead of a large excess which might be utilized for the mechanical removal of sewage from the Lower East river, there appeared to be little or no preponderance of discharge in one direction over the reverse flow.

After giving considerable study to Exhibit IV, it became necessary for the Commission to ask the Survey to clarify certain matters relating to the Lower East river and the question of a preponderance of flow in the Lower East river was again referred to in a letter dated January 21, 1909, and given here as Exhibit V.

EXHIBIT V

New York, January 21, 1909.

Mr. F. W. Perkins, Acting Sup't,
U. S. Coast and Geodetic Survey,
Washington, D. C.

Sir: With reference to your letter of August 14, 1908, regarding the tidal phenomena of the waters of New York harbor, there is one point we have not been able to reconcile with other data at hand: In connection with the resultant flow from Long Island Sound to the Upper Bay you state (p. 23): "There is doubtless a small resultant flow through East river * * * although observations do not conclusively show it. As already stated, the flow through East river is chiefly hydraulic * * *." You then deduce a formula (3) for the velocity at Hell Gate, the resistance factor in the denominator of which accounts for the variation from the theoretical velocity, and say that, "Because this factor greatly exceeds unity it seems probable that the volume transmitted westerly can be not more than 1 or 2 per cent. greater than the volume transmitted easterly" (p. 27).

This theoretical deduction is not entirely clear to us, as the increase in cross-sectional area during the ebb, on which the discharge is largely dependent, is not known and may be large. But after all, the actual gagings that have been made would appear to have more weight in any conclusion than any deductions based upon theory alone, and we would therefore be glad to learn:

1. Whether there are other gagings or considerations not known to us that would invalidate the results obtained.

2. How the gagings made by the U. S. C. & G. C. at 19th street in 1885 (Rep. 1887, App. 15, p. 305), and at 23d Street in 1886 (Rep. 1886, App. 13, p. 424), can be reconciled with the conclusion that the preponderance of the ebb flow is not over 1 per cent.

We would call attention to the explanation of a substantial preponderance in

Rep. 1886, App. 13, p. 421, where it is stated that "there are 3½ feet more water over the sill of Hell Gate when the eastern slope is at maximum," etc., and to p. 429, where certain estimates are given of this excess.

We would also refer to a letter written by Mr. O. H. Tittmann, Superintendent U. S. C. & G. S., June 1, 1903, to Mr. J. A. Lebkuecher, Chairman Passaic Valley Sewerage Commissioners, a copy of which was furnished one of our Commission, in which he estimates the:

Westerly Flow at 19th Street at 4,454,937,257 cubic feet.
Easterly Flow at 19th Street at 4,007,175,676 cubic feet.

adding that "The volume of discharge given above should supersede the data previously furnished."

In short, from every source of information available, including the opinion of pilots and the view which is understood to be held by members of the New York Harbor Line Board, the preponderance of a southward-moving current of, *at least,* 10 per cent., and possibly more is indicated.

Thanking you again for the assistance you have already rendered us and hoping that you may find it convenient to throw light on the above perplexing question, I remain,

Very sincerely,
George A. Soper,
President.

The Commission's questions concerning the resultant flow in the East river, as stated in Exhibit V, were answered by the Survey in a letter dated February 6, 1909, and given here as Exhibit VI.

EXHIBIT VI

Washington, D. C., February 6, 1909.

Mr. George A. Soper,
President, Metropolitan Sewerage Commission of New York.

Sir: Your letter of the 21st ultimo, concerning the resultant flow in East river was duly received.

Before going into numerical details, it may be noted that the current observations mentioned in your letter, viz., those plotted upon p. 423, Report for 1886, and upon plate opposite p. 305, Report for 1887, were continued for too short a period to determine beyond question the net or resultant flow of East river. These plottings indicate the existence of irregularities, or non-periodic features, in the current while the observations were being taken. Upon the page referred to above in the Report for 1886, the plotted curve shows that at Old Ferry Point the east-going stream is much stronger than the west-going, a fact which taken by itself would indicate a net discharge in the easterly direction (or into the Sound), instead of a westerly discharge. This will be partially offset by the fact that at Old Ferry Point the maximum velocity of the east-going stream occurs about an hour after the time of local low water and that of the west-going stream about an hour after the time of local high water. But it is quite doubtful if the excess in cross-section for the west-going stream over that for the east-going stream would be sufficient to account for the observed excess of the eastward velocity over the westward velocity for the particular day of the observations.

Further evidence that the eastward velocity at Old Ferry Point exceeds the westward can be seen upon consulting the curves plotted upon cross-section paper* from observations taken in August, 1885, and which are sent you herewith.

RATIO OF CROSS SECTIONS FOR THE FLOOD AND EBB STREAMS AT THE HELL GATE.

On p. 26 of the letter from this office dated August 14, 1908, it is pointed out that at hour V.3, or the time of the maximum velocity of the west-going stream, the depth of water in the Hell Gate is 1.646 feet more than its mean depth and at XI.3, or the time of the maximum velocity of the east-going stream it is 1.646 feet less than the mean. The mean depth is about 35 feet.

It was also noted that the ratio of the ebb to the flood section could not be as great as $\frac{35+1.646}{35-1.646}$ or 1.1, but would probably be about 1.05. It seems best to here actually compute this ratio.

The ratio in question is

$$\frac{\text{Average value of } \cos\ (30t-159^\circ)\ [35+2.8\ \cos\ (30t-105^\circ)]}{\text{Average value of } \cos\ (30t-339^\circ)\ [35+2.8\ \cos\ (30t-105^\circ)]}$$

where t, in the numerator, varies from V.3—3 to V.3+3 or $30t$ from 69° to 249°; and, in the denominator, from XI.3—3 to XI.3+3 or $30t$ from 249° to $429^\circ=69^\circ$.

2.8 is the amplitude (semirange) of the tide in the Hell Gate and III.5 the high water tidal hour; $105^\circ=30^\circ\times\text{III.5}$.

The above fraction may be written

$$\frac{\int_{x=69^\circ}^{x=249^\circ} \cos\ (x-159^\circ)\ (35+2.8 \cos\ (x-105^\circ)\ d\,x}{\int_{x=249^\circ}^{x=69^\circ} \cos\ (x-339^\circ)\ (35+2.8 \cos\ (x-105^\circ)\ d\,x}$$

where x is written for $30t$.

This equals

$$\frac{70+2.8\int_{x=69^\circ}^{x=249^\circ} \cos\ (x-159^\circ)\ \cos\ (x-105^\circ)\ d\,x}{70+2.8\int_{x=249^\circ}^{x=69^\circ} \cos\ (x-339^\circ)\ \cos\ (x-105^\circ)\ d\,x}$$

$$=\frac{70+2.8\int_{x=69^\circ}^{x=249^\circ} (\cos^2 x \cos 159^\circ \cos 105^\circ+\sin^2 x \sin 159^\circ \sin 105^\circ-\tfrac{1}{2} \sin 2\,x \sin 84^\circ)\ d\,x}{70+2.8\int_{x=249^\circ}^{x=69^\circ} (\cos^2 x \cos 339^\circ \cos 105^\circ+\sin^2 x \sin 339^\circ \sin 105^\circ+\tfrac{1}{2} \sin 2\,x \sin 84^\circ)\ d\,x}$$

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*Not reproduced.

$$=\frac{70+2.8\int_{x=69^\circ}^{x=249^\circ}(.24163\ \frac{\cos 2\,x+1}{2}+.34616\,\frac{1-\cos 2\,x}{2}-.49726\sin 2\,x)\,d\,x}{70+2.8\int_{x=249^\circ}^{x=69^\circ}(-.24163\,\frac{\cos 2\,x+1}{2}-.34616\ \frac{1-\cos 2\,x}{2}+.49726\sin 2\,x)\,d\,x}$$

$$=\frac{70+2.8\left[.24163\ \left(\frac{\sin 2\,x}{4}+\frac{x}{2}\right)+.34616\ \left(\frac{x}{2}-\frac{\sin 2\,x}{4}\right)+.24863\cos 2\,x\right]_{x=69^\circ}^{x=249^\circ}}{70-2.8\left[.24163\ \left(\frac{\sin 2\,x}{4}+\frac{x}{2}\right)+.34616\ \left(\frac{x}{2}-\frac{\sin 2\,x}{4}\right)+.24863\cos 2\,x\right]_{x=249^\circ}^{x=69^\circ}}$$

$$=\frac{70+2.8\Big[(.29390\,x-0.02613\sin 2\,x+.24863\cos 2\,x)\Big]_{x=69^\circ}^{x=249^\circ}}{70-2.8\Big[(.29390\,x-0.02613\sin 2\,x+.24863\cos 2\,x)\Big]_{x=249^\circ}^{x=69^\circ}}$$

$$=\frac{70-2.8\times.29390\,\pi}{70+2.8\times.29390\,\pi}=\frac{72.585}{67.415}=1.077$$

This, then, is, by calculation, the ratio of the ebb-stream section to the flood-stream section at the Hell Gate when the entire tidal period is considered. If the flood and ebb streams were here equally strong it would indicate a westerly flow about 8 per cent. greater than the easterly flow. But the few observations which have been made in the immediate locality indicate that the east-going stream is greater than the west-going, and so it is not safe to infer from the above that the westerly discharge through the Hell Gate exceeds the easterly.

THE LENGTH OF THE EAST RIVER AN IMPORTANT FACTOR

Since the tidal rise and fall in the Upper Bay and in Long Island sound is nearly harmonic in time (*i. e.,* it nearly obeys the law of sine or cosine of a time angle) and since the current in East river is nearly hydraulic, it follows that the velocity set up in East river, taken as a whole, should be the same upon the flood as upon the ebb. In other words, the difference in head will be the same in like phases of the two streams. But formula (3), p. 24,* shows that when resistance is taken into account, the velocity, where greatest, depends chiefly upon the fact that East river has considerable length; for, if its length were only a few hundred feet, the maximum velocity would be as indicated upon p. 25, viz., 16.63 feet per second.

The following rough computation of the resistance will show that the denominator in (2) or (3) is considerably greater than unity.

From Throgs Neck to the western side of Governor's Island is 17 statute miles =89,760 feet. The average depth is about 40 feet. These estimates make

$$L=89{,}760;\ \frac{P}{\Omega}=\frac{1}{40};$$

and so putting $\zeta'=0.007565$,

$$1+\zeta'\,\frac{P}{\Omega}\times L=1+0.007565\times 2244$$

$$=1+1.70=2.70$$

$\therefore v=16.63\div\sqrt{2.70}=16.63\times .6085=10.12$ feet per second $=$ 5.99 knots per hour.

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*Page 567, this report.

This is not greatly in excess of actual ordinary maximum current in the Hell Gate. The above rough computation shows that the velocity is kept down to that actually occurring by the resistance due to the bed and banks of East river. The resistance occurs, of course, in varying amounts in different portions of the river. The computation is for a uniform channel. The actual channel would doubtless offer greater resistance than the one here assumed because of the bends and sudden changes in cross-section.

IN THE WESTERN END OF EAST RIVER THE FLOOD STREAM HAS THE GREATER CROSS-SECTION, IN THE EASTERN END OF THIS RIVER, THE EBB OR WEST-GOING STREAM HAS THE GREATEST CROSS-SECTION.

The Greenwich lunar times of high and low water (tidal hours) at Governor's Island are XII.73 and VI.95, respectively, same quantities at Willet's Point are III.69 and X.10. The time of the maximum east-going stream is X.5 at Throgs Neck and XII near the western side of Governor's Island. But the time for greater portion of the river falls between XI and XI.5, and has been taken as XI.3. (See Figs. 11 and 13, opp. p. 356, Coast and Geodetic Survey Report for 1907.) The times of the west-going stream are the above diminished by 6 hours. Hence, the maximum value of the west-going stream at Throgs Neck follows local high water by only IV.5—III.69 =0.8 hour. The maximum value of the east-going stream at Governor's Island follows local high water by only XII.73—XII=0.7 hour.

The streams thus attaining their maximum values at nearly the times of local high water, it follows that the west-going stream at Throgs Neck has a considerably greater cross-section than the east-going, while the reverse is true for the Governor's Island end.

The point in East River where the maximum streams occur at the time of local half-tide level is about the middle of Blackwell's Island. Westward from this point the east-going stream has the greater cross-section and eastward from this point the reverse is the case.

Currents observed at 21 stations where results are available between Blackwell's Island Light and Throgs Neck show the westerly velocity to be only about 0.77 times the easterly velocity. The range of tide over this region being 6.8 feet and the depth 40, the ratio of sections will be $\frac{40-3.4}{40+3.4}=0.84$. This ratio compared with that obtained from observation indicates easterly resultant flow. The excess of the easterly over the westerly velocity is apparent upon consulting the blue prints* of the plotted observed velocities.

Current observations taken between the southern end of Blackwell's Island and Wallabout Bay show, on an average, no difference between the velocities of the east-going and west-going streams. At the middle of this reach the times of half-tide level are X.9 and IV.9. The times of the east-going and west-going streams are XI.3 and V.3 respectively. Hence, in this reach where the times of half-tide level about coincide with the times of maximum current (the locality therefore being one where the two streams have nearly equal cross-sections) the two streams have practically the same velocities. The observed velocity of the west-going stream comes out from 18 stations as 1.00 times that of the east-going. This indicates that a trifle more water flows easterly than westerly.

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*Not reproduced.

Between the Brooklyn Bridge and Governor's Island the velocity of west-going stream is for 17 stations 1.23 times that of the east-going. Little importance should be attached to this. It doubtless shows that portions of the fresh surface water of the Hudson are deflected to the eastward of Governor's Island and pass out through Buttermilk Channel.

The two stations near the northern end of Blackwell's Island at which several days' continuous observations were obtained, and for which blue prints are furnished, show the velocities of the two streams to be nearly equal, the west-going stream being 1.01 times the east-going. Taking 6 stations around Blackwell's Island into consideration, this ratio becomes 1.03. Here the time of half-tide level almost exactly coincides with the time of the maximum flood or ebb current. This fact taken in connection with the current observations indicate that the volumes passing each way are sensibly equal, the west-going being 1.03 times the east-going.

CONCLUSIONS

It can hardly be said that our observations upon the currents indicate a net discharge in either direction through the Hell Gate. They indicate that, as a rule, the stream having the larger cross-section has the smaller velocity, and vice versa, thus leaving the question of the amount of net discharge uncertain.

Mitchell in his early determination (Report for 1871, p. 131), gives for the volumes passing through East River at Wall Street section: Flood, 4,341,100,000 cubic feet; ebb, 4,383,500,000 cubic feet, or a difference of only 1 per cent. See also pp. 168-173, Report for 1876.

Observations indicate that for sections between Wallabout Bay and the southern extremity of Blackwell's Island the flood volume is quite as great as the ebb volume (p. 8,* this letter).

Observations taken between Blackwell's Island light and Throgs Neck show that the flood stream is decidedly stronger than the ebb. A rough computation (p. 7,† this letter), indicates when the cross-section of the two streams are compared there can hardly be a westerly net discharge through the East river.

The observations around Blackwell's Island, taken by themselves, indicate a small net westerly discharge, the west-going volume being about 1.03 times the east-going. It seems probable that this item is more important in deciding the question than any one of the others contained in this letter.

On p. 422, Report for 1886, Mitchell says: "From Table 3, and the Diagram B that illustrates it, one may estimate for the point intermediate between 84th street and Polhemus Dock a difference of 3½ feet between the *stages* of alternate maximum *slopes, i. e.,* there are 3½ feet more water over the *sill* of Hell Gate when the western *slope* is at maximum than there is when the eastern slope is at maximum. We have reiterated the foregoing statement because it is the keynote of our theme and gives no uncertain sound."

But the flow through East river will not vary as the cross-section at Hell Gate of the flood or ebb stream. For it is evident from formula (3), p. 24,‡ letter of Aug. 14, 1908, that the smaller the section at this point, the other sections of the river remaining as before, the greater must be the velocity there, because l_1, or the distance through the "gate," is a small fraction of l_2, l_3, etc., the lengths of the other reaches of the river. As the third and subsequent terms of the denominator of (3) become the important terms, the velocity v at the Hell Gate varies approximately inversely as Ω, or the section at that place varies. But the cross-sections for the other and longer reaches, Ω_2, Ω_3, ... are larger for one stream than for the other; formula (3) shows that, other things being equal, increases in such sections increase the velocity, v, through Ω_1. By varying the cross-sections for the varying stages of the tide, and by giving them proper weights in the denominator of formula (3), it seems quite possible that the westward velocity through the Hell Gate may so fall short of the eastward velocity that the ebb volume shall exceed the flood volume by only a small amount, although the section of the former is 1.077 times that of the latter (p. 4, this letter). As already stated, observations seem to indicate that the ebb velocities here are somewhat less than the flood velocities.

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*Page 577, this report. †Page 577, this report. ‡Page 567, this report.

Attached are 8 blue prints and 1 plotting of current observations.*

Respectfully yours,
O. H. TITTMANN,
Superintendent.

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*Not reproduced.

SECTION II

CORRESPONDENCE RELATING TO NEW ESTIMATES OF THE FLOW OF THE EAST RIVER

It having come to the knowledge of the Commission that extensive observations of the flow of the East river at Hell Gate had been made by the Engineer Department of the U. S. Army, a request for permission to utilize these data was made to Colonel William M. Black, under whose direction the observations had been prepared. The data had not hitherto been computed to show the total volume of water passing through the Lower East river, the object of the studies having covered another scope relating to the local improvements of the channels. The permission was granted and the Commission undertook to re-estimate the flow of water passing. The fundamental data consisted of a number of tide gauge records covering a long period of time and co-related in part with current observations extending over a briefer interval. When the computations were completed the result showed a considerable excess flow of water southward through the East river.

The matter was referred by the Commission to the Survey in a letter dated May 13, 1913, with the request that the Survey give the estimate a critical examination and express an opinion as to the accuracy of the results. This letter is here given as Exhibit VII.

EXHIBIT VII

New York, May 13, 1913.

Prof. O. H. Tittmann, Director,
U. S. Coast & Geodetic Survey,
Washington, D. C.

Dear Sir: Your attention is invited to the enclosed statement describing studies made partly by Colonel William M. Black, Corps of Engineers, U. S Army, and partly by this Commission, concerning the volumes of water passing through the East river in the vicinity of Hell Gate. A detailed account of the field and office methods used in obtaining these results will be found in Professional Memoirs, Corps of Engineers, U. S. A., for May-June, 1913.

This Commission would value your critical examination of this study and an opinion as to the accuracy of the results. You will observe that the results appear to confirm the figures announced by Prof. Henry Mitchell in 1886, as a result of his studies, and that they do not agree either with the results of the investigations made by the U. S. Coast Survey in 1908 and transmitted by the Survey in a statement to this Commission dated August 14, 1908, or with the results of the studies made by Mr. H. deB. Parsons of this Commission and described in the April number of the Proceedings of the American Society of Civil Engineers.

Very sincerely,
George A. Soper,
President.

The report on the computations prepared by Ernest F. Robinson, Assistant Engineer on the Commission's staff, who collected the original data under the direction of Colonel Black, and later had charge of the computations for the Commission, dated May 1, 1913, is here given as Exhibit VIII.

EXHIBIT VIII

May 1, 1913.

Dr. George A. Soper,
President, Metropolitan Sewerage Commission of New York.

Dear Sir: I have the honor to report upon an investigation of the ebb excess flow in the East and Harlem rivers, New York harbor.

The question of preponderance of flow towards New York bay from Long Island sound is a disputed one. It was first investigated by Henry Mitchell, assistant, U. S. Coast and Geodetic Survey, in 1886. In his report, he first demonstrated by the nature of the tidal phenomena at either entrance to the harbor, that such an excess should exist, then by field observations he established its magnitude, as about 400,000,000 cubic feet in each tidal cycle of 12 lunar hours (12h. 25m. solar time).

Since the publication of this report there have been numerous discussions upon the subject, and the Coast Survey itself has rejected this figure as excessive, substituting a value of *100,000,000 "or less" as the probable excess. Mr. H. deB. Parsons, of the Metropolitan Sewerage Commission, recommends a figure of 80,000,000 cubic feet (Proc. Am. Soc. C. E., April, 1913, page 715). It is significant, however, that of all these later estimates, *not one* is based upon actual field observations.

Professor Mitchell's theoretical demonstration was extremely simple, and admits no doubt that such excess *must* occur, leaving only a question as to its amount. The range of tide at Throgs Neck, the Long Island sound entrance to the harbor, is greater than that at Sandy Hook, the southern entrance. Furthermore, the tidal wave, in its passage through the sound, is delayed, so that high water occurs 3½ hours later at Throgs Neck than at Sandy Hook.

Owing to the difference of range, the tide at Sandy Hook does not rise as high as that at Throgs Neck, neither does it fall so low. The greatest difference of level, or slope, on the northbound tide, occurs about 1½ hours before high water at Sandy

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*Letter of Mr. F. W. Perkins, Acting Supt. to Dr. Soper, President Metropolitan Sewerage Commission, Aug. 14, 1908.

Hook, and on the southbound tide, 1 hour after high water at Throgs Neck. The heights at these times are as follows:

	Elevation Sandy Hook	Elevation Throgs Neck	Difference	Mean elevation
Maximum slope north......................	+2.0	—3.4	5.4	—0.7
Maximum slope south......................	—2.0	+3.4	5.4	+0.7

At the time of greatest slope south, therefore, it is seen that, although the slope is the same, elevations throughout the East river are more than one foot higher than on the corresponding north slope. The southerly slope, therefore, having a deeper channel and consequently a greater hydraulic radius, must generate a higher velocity, and as this velocity acts through a larger cross-sectional area, the rate of discharge must be correspondingly increased.

This difference of stage elevation, between slopes produced at the times of northerly and southerly flow, holds in favor of the latter for the whole period of the southbound current, consequently the entire volume passed through the East river during this period *must* be in excess of that of the northerly flow.

During 1910-1911 the Engineer Department, U. S. Army, made extensive field observations in the vicinity of Hell Gate, under the direction of Col. W. M. Black, Corps of Engineers, U. S. Army, with a view to relieving the currents which impede navigation through this portion of the East river. These observations include very complete gaugings in the Harlem and East rivers and auxiliary channels, and an investigation of tidal phenomena in this vicinity. Through the courtesy of Colonel Black the records of these observations are placed at the disposal of this Commission, and form the basis of the present investigation.

The flow in the East and Harlem rivers and the subsidiary channels is hydraulic; *i. e.,* caused by the head or difference of level at either end. However, the application of the laws of stream flow to these channels is complicated by the constantly changing heads produced by the progress of the tidal wave. It is further complicated by the varying height of these waves caused by the ever-changing positions of the sun and moon with respect to the earth, by the interference of the tidal waves entering the East river by way of Sandy Hook and Throgs Neck, respectively, and by the varying levels of the Atlantic ocean and Long Island sound under wind action.

Owing to these varying factors, discharge measurements taken in the same channel even on succeeding tidal cycles may differ widely, so that comparisons between gaugings of different channels, unless made simultaneously, are absolutely unreliable. A combination of circumstances at the time of a gauging may so change conditions as to cause the entire disappearance of the net ebb flow, if such exists, or to reverse its direction.

The simultaneous observations of current velocities at the required number of stations would have necessitated a larger party and equipment than was available, and, even had this been done, the results would have represented only one out of the many combinations of tidal conditions which may exist in this locality. The *mean* discharge for each channel, therefore, was adopted as the basis of comparison.

Since the velocities and consequently the discharges result from the slope and stage, it may be assumed that similar tidal conditions as to the height and slope will cause equal discharge rates. If, then, simultaneously with the gauging of a channel, the tidal heights at both ends be continuously observed, the resulting records will show the heads or slopes produced at each moment of the observation, as well as the discharge rates generated by these slopes.

A relation may now be found between slope and discharge, which, if applied to a mean tide with its slopes, will give the mean tidal discharge of the channel. Velocity area observations are expensive and require great care if accurate results are to be obtained. Furthermore, they are constantly interrupted by traffic, and to continue them long enough to obtain a true mean discharge is clearly impracticable. On the other hand, observations for tidal height may be made continuously, accurately and inexpensively by automatic tide gauges, requiring little attention, and entirely independent of weather conditions.

The period of observation is one period of the moon, twenty-nine days, or fifty-seven consecutive tidal cycles, and is known as a "lunation."

The construction of a mean tidal curve from the record of an automatic gauge is a matter of considerable labor, but comparative simplicity. The record is in the form of a long strip of paper on which the varying heights of tide are represented by the distances from the base line of a sinuous curve traced by the recording pencil. Time is measured at right angles to the height ordinates, or along the base line mentioned above. In the Stiehrle Gauge, which was used in these investigations, the scale is one inch equals one foot of height and one hour of time. At intervals of a day or two are entries upon the record of the correct time, made by the caretaker of the gauge in his visits. From these notes the time is corrected for the entire record, and the times of the successive lunar transits are marked.

The exact time of high and low water is determined, the heights measured and tabulated in separate columns. The intervals between high and low water are then divided into six equal parts, representing, approximately, lunar hours, and the height of the curve is determined at each of these hours and tabulated, as explained for high and low water. The luni-tidal intervals, or the times elapsing between the moon's transit and high and low water, respectively, are also determined and tabulated in separate columns. The mean of the fifty-seven items in each column determines the elements of the mean tidal curve; *i. e.,* the lunar times of high and low water, and the heights of the curve at high and low water and at ten intermediate points.

The study of the curve thus constructed shows, free from all irregularities, the characteristic tidal conditions of the station. A storm tide during the period of observation has no appreciable effect upon the mean curve when averaged with so many other tides. The range of such a curve is found to be practically constant, as is also the shape of the curve, but the stage (=mean sea level) or elevation midway between high and low water, varies greatly at different seasons of the year, the discrepancy sometimes exceeding half a foot. The mean of all these stages, however, for a long period, is the plane of mean sea level, as established by the Coast Survey.

Furthermore, mean curves obtained simultaneously lie at the same stage, although this stage may vary with the season. For purposes of comparison, therefore, it is permissible to use mean curves obtained at different times, provided that they first be adjusted so as to bring their mean stage to the plane of mean sea level.

If two such curves, say Lawrence Point and Hallet's Point, be plotted upon the same time ordinates, the difference of level between these points at any time is represented by the vertical distance between the curves at that time. The discharge rate at this same time is known from the discharge curve. A relation between the two may now be found.

It is clear that this relation must be shown in a manner entirely empirical. Confusing factors of changing head, etc., enter into the problem so as to make any mathematical determination based upon the laws of stream flow entirely out of the question.

Moreover, in attempting to relate discharge to slope, it must be remembered that, in the case of immense volumes of water in motion, the laws of inertia and momentum must exert a powerful influence. Changes must be brought about gradually, and existing conditions of flow may often be due to slopes which have changed or ceased to be.

Slack water, or zero current, does not coincide with the time of crossing of the curves, or zero slope, but occurs some time later. In other words, the momentum of the moving water is sufficient to keep it in motion not only through the zero slope, but until a marked negative slope has accumulated. In the meantime, the water has been flowing against a head, or uphill. The *effective head,* therefore, becomes zero at slack water, and for a period before and after slack, the effective, rather than the actual head, must be considered.

The effective head is greater than the actual before slack, owing to the momentum of the water, and, by reason of the inertia of the water on the change of tide, it lags behind the actual head for a considerable period after slack, until the velocity has picked up.

The tidal head, corrected for momentum, is the varying factor in the discharge formula for a constant channel section, and may be used in a graphical diagram in place of the slope, which results from the head. The channel section, however, is not constant, varying with the stage of the tide, which is thus introduced as a new variable factor. Of a number of parallel slopes, that produced at the highest stages will generate the greatest discharge rate. In the construction of a graphical diagram, therefore, both slope and stage must be taken into account.

From the field records, the discharge rate and the tidal heights at both ends of the channel are known. The difference between the two heights is the head. A diagram may now be constructed, with heads as ordinates and observed discharge rates as abscissas. At the intersection of the coördinates representing observed head and simultaneous discharge rate, is written the actual tidal elevation at Lawrence Point, which, with the known slope, determines the stage throughout the channel. Similarly, points are plotted for each quarter hour, say, of the observation. Curves are then drawn through the points representing equal elevation at Lawrence Point, one for each even foot of the stage. Logarithmic plotting is employed, it having the great advantage for work of this character that the "curves" become straight lines and are parallel.

To reverse the process and obtain from the diagram the discharge rate corresponding to given elevations at both ends of the channel, the procedure is as follows: Find upon the left-hand margin the difference of height, or head; follow the horizontal line through this point to the diagonal representing the tidal height at Lawrence Point; vertically above this intersection, on the upper margin, will be found the required discharge rate. Separate diagrams are constructed for both the flood (north) and the ebb (south) flow.

Four sets of such diagrams were constructed: For Hell Gate (Main Channel), Little Hell Gate, Harlem Kills, and the Harlem river (217th street), based upon continuous current observations for three days (6 tidal cycles) at each point, excepting Hell Gate, where two cycles of 13 hours each were observed, upon a spring and a neap tide respectively.

Having established a relation between slope, stage and discharge, it is now possible to determine the *mean* discharge by means of the diagram, making use of the mean tidal curves of the channel in question. It only remains to assure ourselves that the curves actually represent *mean* conditions. Each curve is the mean of 57 consecutive tidal cycles, or one period of the moon, in all its phases. Were the moon the only heavenly body to be considered, this period should yield a true mean curve. However, the sun, and, according to the Coast Survey, 34 other heavenly bodies, are considered in the compilation of their tide tables.

Only the effect of the sun, however, need be considered here, as even its influence is less than half that of the moon, and the other elements do not enter with sufficient influence to merit consideration. The effect of the sun, in its varying distances from the earth, seems to result in a raising or lowering of the whole tidal curve, without altering its *shape* or *range*. Thus, if in any particular month the high waters are higher than in another, the low waters are correspondingly higher, and the stage is raised. A mean of the mid-stages for a solar period (one year) is the plane of mean sea level. Since the shape and range of one lunation (57 cycles) do not materially differ from those of any other, it may be considered that any good mean curve of a station for one lunation, with its mean height adjusted to the plane of mean sea level, represents mean conditions at that station sufficiently well for the purpose.

Again, for curves obtained *simultaneously*, the mean height is always the same, and any conditions which affect one, influence the other to the same extent. Wherever possible, the comparative curves used in this investigation are of simultaneous observation, particularly for the main channel of Hell Gate, which carries the greatest flow, and is the predominant factor in the problem.

From the mean tidal curves of Lawrence Point and Hallet's Point, therefore, the heights at intervals of half an hour are measured, and from these the corresponding discharge rates are obtained from the discharge diagram. These rates are erected as ordinates to the "discharge curve," whose abscissas are time and whose ordinates are rates of discharge. These ordinates are positive, or measured up from the horizontal axis, during the flood flow, and negative, or measured down, during the ebb flow. The curve passes through zero at slack water.

The area lying between the curve and its horizontal axis, being the product of time by rate of discharge, represents the total *volume* discharged in one tide. Integrating this curve for Hell Gate, the volume discharged on a mean tide is found to be as follows:

HELL GATE DISCHARGE

Ebb (South) volume	4,482,665,000 cu. ft.
Flood (North) volume	4,221,170,000 "
Ebb excess	261,495,000 cu. ft.

From the observed data in Little Hell Gate, Harlem Kills and the Harlem river, mean tidal curves, discharge diagrams, and discharge curves were constructed for these channels.

From the discharge curves were determined the total flood and ebb volumes in each of these channels for one tidal cycle. The ebb flow in all cases is the greater.

LITTLE HELL GATE

Ebb (West)	326,588,700 cu. ft.
Flood (East)	183,747,900 “
Ebb excess	142,840,800 cu. fc.

HARLEM KILLS

Ebb (West)	113,059,170 cu. ft.
Flood (East)	57,520,546 “
Ebb excess	55,538,624 cu. ft.

HARLEM RIVER, 217TH STREET

Ebb (North)	252,366,000 cu. ft.
Flood (South)	207,912,000 “
Ebb excess	44,454,000 cu. ft.

In view of the generally accepted figures these values appear to be too large, but they must be regarded as the result of careful field work with observations extending over a period of two years, while other determinations are based upon theory alone.

When one considers that in the Hell Gate channel alone the mean head for the duration of the ebb is 1.88 that of the flood, and that the sectional area at the strength of the ebb is 8 per cent. greater than the corresponding flood area, then the ebb excess of 6.2 per cent. of the flood volume does not seem unreasonable. Nor, in view of the excess of ebb area over flood at strength in Little Hell Gate and Harlem Kills, of 57 per cent. and 105 per cent. respectively, does an excess of ebb flow nearly equal to the total flood volume appear absurd. The following table shows for each of these channels the increase of sectional area and of head both at the strength of the ebb and flood, and of a mean for the duration of flow. The ebb excess, as a percentage of the flood volume, is also tabulated.

TABLE CX

Ratios	Hell Gate	Little Hell Gate	Harlem Kills	Harlem river
Ebb head to flood head at strength	1.5	0.64	0.68	1.0
Ebb head to flood head, mean for duration of flow	1.88	0.68	0.74	1.08
Ebb area to flood area at strength	1.08	1.57	2.05	1.08
Ebb area to flood area, mean for duration of flow	1.03	1.16	1.26	1.07
Net ebb excess to total flood volume	.062	.78	.966	.21
Duration, ebb to flood	1.00	1.22	1.14	1.04

Of the flood volume in the East river, towards Long Island sound, a small portion enters from the Hudson river by way of Harlem river. This flow reaches the East river through Harlem Kills and Little Hell Gate, although the latter channel carries a small portion of the flow which comes up from the Lower East river. By far the greater part of this discharge, however, is through the main Hell Gate channel, between Astoria, L. I., and Ward's Island. On the ebb, Harlem Kills carries nearly half the flow of the Harlem river, and Little Hell Gate carries an increased percentage of the flow of the Lower East river.

The discharge of the Upper East river, north past Lawrence Point, is equal to the combined volumes from Hell Gate, Little Hell Gate and Harlem Kills. The discharge south is, in a like manner, equal to the combined ebb flow of these three channels. Past 88th street, north, the flow of the Lower East river is equal to that as found for the Upper East river, less that which enters from the Harlem river, which does not pass 88th street. The flow south past 88th street is equal to that south past Lawrence Point, less that which escapes through the Harlem, and which, therefore, does not pass 88th street.

But at the commencement of the south flow, the water surface in the basin between Lawrence Point and 88th street is nearly five feet higher than at its completion. The water occupying this space, or the tidal prism, which was in place at the commencement of flow, and, therefore, did not enter past Lawrence Point, must have run out past 88th street, increasing this flow by the volume of the prism. However, on the reverse current, this same amount will enter past 88th street and raise the water to its original height, but *will not* flow out past Lawrence Point. Hence the effect of this tidal prism will be to increase both the flood and ebb discharges past 88th street by an *equal* amount, leaving the *net excess* unchanged.

The ebb excess for the Upper East river, therefore, is the combined excesses of Hell Gate, Little Hell Gate, and Harlem Kills, and for the Lower East river it is the same amount, diminished by the ebb excess of the Harlem river.

The volumes of flow as determined for Hell Gate and the auxiliary channels, when combined in the manner indicated above, give the following results:

	Flood (Towards L. I. Sound)	Ebb (Towards N. Y. Bay)
Hell Gate (Main Channel)	4,221,170,000 cu. ft.	4,482,665,000 cu. ft.
Little Hell Gate	183,747,900 “	326,588,700 “
Harlem Kills	57,520,546 “	113,059,170 “
Sum	4,462,438,446 cu. ft.	4,922,312,870 cu. ft.
Total flood volume		4,462,438,446 “
Net ebb excess, Upper East river		459,874,424 cu. ft.
Net ebb excess, Harlem river		44,454,000 “
Net ebb excess, Lower East river		415,420,424 cu. ft.

Professor Mitchell in 1886 obtained the following values:

Net ebb excess, Upper East river	432,000,000 cu. ft.
Net ebb excess, Lower East river	418,000,000 “
Difference (=Ebb excess, Harlem river)	14,000,000 cu. ft.

The net ebb excess of the Lower East river represents the amount of water discharged into New York bay by the East river in one tidal cycle, over that withdrawn in the same cycle, while the excess of the Upper East river represents the net gain to the whole harbor of clean sea water drawn from the sound.

Respectfully submitted,
E. F. Robinson,
Assistant Engineer.

Under date of October 9, 1913, the reply of the Survey is given to the Commission's request for an opinion as to the accuracy of the re-estimation of the flow of water through the East river, based on Colonel Black's data. This reply is here given as Exhibit IX.

EXHIBIT IX

October 9, 1913.

DR. GEORGE A. SOPER,
President, Metropolitan Sewerage Commission,
17 Battery Place, New York City.

SIR: In compliance with your request originally made on May 13, 1913, that an examination be made of a report by E. F. Robinson, Assistant Engineer, concerning the gauging of the tidal streams in the East and Harlem rivers, I submit the following remarks and criticisms.

Replying first to the statement made upon pp. 1, 2 of this report, viz., "It is significant, however, that of all these later estimates, *not one* is based upon actual field observations," it will probably suffice to refer to a letter from this office to Dr. Soper, dated Feb. 6, 1909, particularly, pp. 7-11.

In this same letter a computation is made based upon the known depths and tides which shows (p. 4) that in the Hell Gate (near Frying Pan) the ratio of the ebb-stream section to the flood-stream section is about 1.077. But (see p. 10) it is not reasonable to suppose that this value represents the ratio of the ebb to the flood volume because such ratio must depend upon all sections of the East river between Governor's Island and Lawrence Point.* In fact the few observations which have been made in this immediate locality indicate that the east-going stream is the stronger. The plottings sent with the letter of February 6, 1909, show clearly that off Old Ferry Point the velocity of the east-going stream exceeds that of the west-going. As a consequence the ratio must probably be reduced to a ratio nearer unity. Around Blackwell's Island the ratio of the ebb-stream section to the flood-stream section is very nearly unity. The observed velocities at six stations around this island indicate that the required ratio for the tidal volumes is 1.03, which appears to be a reasonable value (p. 10). The ratio which Mr. Robinson's figures give for a section somewhat further to the eastward is 448...÷422...=1.06. Mitchell's values for a section off 19th street, probably based chiefly upon the observations taken in 1885 (Coast Survey Report, p. 36, for 1886), give 445...÷401...=1.11 as this ratio. The values of the excess of ebb over flood derived from observations taken off 19th street and off Old Ferry Point in 1885, and given upon p. 426, Coast Survey Report for 1886, indicate that the ratio of the ebb volume to flood volume is somewhat less than 1.11. The observations taken in 1886 (Oct. 4-7) were, of course, not included in Mitchell's estimate dated June 25, 1886. The brevity of the 1885 and 1886 observations taken in connection with the irregularities of the current as shown upon p. 423, Report for 1886, and opposite p. 305, Report for 1887, preclude the accurate determination, from them alone, of the resultant flow, which is a comparatively small quantity.†

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*See also formula 3, p. 567, letter from this office to Dr. Soper, dated Aug. 14, 1908; also letter to Kenneth Allen, dated Sept. 30, 1908.

†See pp. 575, 576, letter to Dr. Soper, Feb. 6, 1909.

Returning now to Mr. Robinson's report, it will be noted (p. 10) that for his Main-Channel section (near Negro Point Bluff) the current observations comprised two periods of 13 hours each. As the observations do not accompany Mr. Robinson's report, nor are they given in the more extended paper by Colonel Black (Professional Memoirs, Corps of Engineers, U. S. A., May-June, 1913), it is impossible to judge concerning the accuracy of the determination and especially in reference to the ebb excess, which is a comparatively small quantity.

The computations and estimates which have been furnished by this office were made without especial reference to Little Hell Gate, Harlem Kills and Harlem river, as we possess very few observations made in these straits.

On account of the shallowness of Little Hell Gate and of Harlem Kills, there can be no doubt but that the ebb excess through these two passages is considerable.

From pp. 13, 14 of Mr. Robinson's report the following values of ebb and flood volumes are taken:

LITTLE HELL GATE

Ebb (West)	326,588,700 cu. ft.
Flood (East)	183,747,900 "
Ebb excess	142,840,800 cu. ft.

HARLEM KILLS

Ebb (West)	113,059,170 cu. ft.
Flood (East)	57,520,546 "
Ebb excess	55,538,624 cu. ft.

HARLEM RIVER—217TH STREET

Ebb (North)	252,366,000 cu. ft.
Flood (South)	207,912,000 "
Ebb excess	44,454,000 cu. ft.

If the Little Hell Gate and the Harlem Kills values be added together we have

LITTLE HELL GATE AND HARLEM KILLS

Ebb (West)	439,647,870 cu. ft.
Flood (East)	241,268,446 "
Ebb excess	198,379,424 cu. ft.

If these determinations are correct, it is a little surprising that of the 198,379,424 cu. ft. excess from Little Hell Gate and Harlem Kills only 44,454,000 cu. ft., or less than one-fourth part, pass through the Harlem river to the Hudson, whereas considerably more than half of the ebb or flood volume passing these two straits passes through the Harlem river.

The ebb or north-going volume of the Harlem river is undoubtedly greater than the flood or south-going volume because during the north-going stream the average depth of the river throughout practically its entire length is greater than during the south-going.

The ebb stream from Little Hell Gate entering the basin-like expanse around Great Mill Rock must lessen the fall or hydraulic head through the main channel, thus tending to decrease the ebb velocity occurring between Astoria and Ward's Island, and at points further eastward. The flood velocity in the Hell Gate is likewise diminished by the existence of Little Hell Gate, but not to the same extent. This is probably one of the reasons why the velocity of the east-going stream in the main channel exceeds that of the west-going, a fact which most observations indicate.

The chief reason for believing that the flood and ebb volumes are nearly equal for any given section of the East river from, say, Brooklyn Bridge to Lawrence Point (Little Hell Gate included) is that whereas the water is generally deeper on the ebb stream than on the flood for sections eastward and northward from Blackwell's Island the reverse is true for sections to the southwestward. This has been already explained in the letter dated Feb. 6, 1909, pp. 6, *et seq.*

In order to see that the flow depends upon a channel throughout its entire length, and not upon a particular constricted portion where the velocity is greatest, it is only necessary to note that if an obstruction like a dike or jetty were built out from either bank of a uniform channel of considerable length there reducing the cross-section to one-half of its value elsewhere along the channel, the amount of flow due to a given head and for a given period would not be seriously affected by such obstruction although the velocity for the particular cross-section would be doubled.

In the case of the East river, and notably its eastern portion, the area of any particular cross-section varies as the tide there rises and falls. But it does not follow that the ratio between the ebb and flood volumes for this river will be that of the ebb and flood cross-sectional areas at the particular section taken; *e. g.,* in the Hell Gate proper. The resistances of all portions of the river bed enter into the question of tidal volumes. (See letter dated Aug. 14, 1908, formula (3), p. 24;* and letter dated Feb. 6, 1909, pp. 10, 11.)

In regard to the methods used by the Engineers in correlating the current observations with the tidal records, and described in Colonel Black's paper and also in Mr. Robinson's report, a few statements may be submitted:

If the relation between "difference of head" and "discharge" at a given section are to be represented by means of equidistant parallel straight lines drawn upon logarithmic cross-section paper, the implied assumptions are: That the velocity at any particular time is proportional to some power (say the power ½) of the difference of head, and that the effective sectional area is the mean-half-tide-level section multiplied by a factor whose logarithm is proportional to z, z denoting the ratio of the height of the tide reckoned from half-tide level to the depth at the time of half-tide level. This is nearly equivalent to saying that the factor should be proportional to $1+z$ since

$$\log (1+z) = M \left(z - \frac{z^2}{2} + \frac{z^3}{3} - \dots\right)$$
$$= Mz$$

when z is small in comparison with unity. That the factor should be of the form $1+z$ is a natural assumption and one which must be fairly good, especially when the banks of the stream between low and high-water marks are nearly vertical, the range of tide small in comparison with the depth, and the entire length of the strait connecting the two tidal bodies not long enough for the bed resistance to become too pronounced. For long straits, like the East river, the velocity depends upon the cross-section as well as upon the head, as formula 3, letter dated Aug. 14, 1908, shows. In the case of a long and nearly uniform canal the tendency is to approach a value of which one factor is the square root of the hydraulic mean depth (formulas of Prony,

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*Page 567, this report.

Etelwein, Tadini and others*), and so the discharge, corresponding to a given slope, must contain not only the factor $1+z$ but $\sqrt{1+z'}$ where z' is a fraction denoting the amount of hydraulic mean depth increase due to the stage of the tide, the latter being measured from half-tide level.

That the relative velocities at a given section are proportional to the square root of the difference between two near-by heights, as is implied in the straight-line plottings on logarithmic cross-section paper, is probably nearly true, because the scheme of observing does not contemplate the comparison of the velocities of one section with those of another. It is to be borne in mind, however, that the actual flow across any given section, or in any given reach, of East river is dependent upon all portions of the river from one end to the other. If the expansions and contractions of the channel are so gradual that no considerable energy is for that reason lost, the case is quite different from the case of a compound reservoir whose component parts are connected by means of small straits, and where most of the energy is lost. In this connection references may be made to pp. 253, 254 and 263, Coast and Geodetic Survey Report for 1907.

It seems to be tolerably certain that more current observations should be made at the gauging section near Negro Point Bluff before the resultant discharge of East river can be determined with any considerable accuracy, and in accordance with the scheme outlined in Mr. Robinson's report.

So far as this question alone is concerned, matters would doubtless be simplified by selecting one or more gauging sections between, say, Hallett's Cove and the Brooklyn Bridge.

In order to settle this question in as satisfactory a manner as possible, measurements should be made at times when there is comparatively little fresh water coming down the Hudson, and also at times when the amount is considerable. This would enable one to ascertain whether or not the fresh water coming through the Harlem has any sensible bearing upon the question of net discharge in lower East river.

Respectfully,
F. W. Perkins,
Acting Superintendent.

The Survey's answer states as tolerably certain that more current observations should be made before the resultant discharge of the East river can be determined with any considerable accuracy in accordance with the scheme submitted to the Survey for consideration. In the Survey's opinion, in order to reply to this question satisfactorily, measurements should be made at other times than those included in Colonel Black's series, especially at times when there is comparatively little fresh water coming down the Hudson and times when the amount is considerable, the application to this point being to ascertain whether or not the fresh water coming through the Harlem has any sensible bearing upon the question of net discharge in the Lower East river.

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*See Bovey's Hydraulics, 2d ed, pp. 144–155 and Ch. III.

CONCLUSION

The studies indicated in the foregoing correspondence show only a part of the investigations which have been made by the Commission into the tidal phenomena of New York harbor. Other work has consisted of various extensive series of long-continued float observations as described in part in the report of the Commission dated April 30, 1910, and more fully set forth in Chapter IV, Part IV of this report.

For a year observations were made of the salinity of the water at 11 stations located in the more important parts of the harbor, the object of this work being to determine needed information on the circulation of the ocean and river waters. A brief description of the salinometer work will be found in the Commission's report of April 30, 1910. The original data were too voluminous to print.

The net result of all the tidal studies is in harmony with the opinions derived from the exhaustive analytical investigations of the water which the Commission has carried on. Every essential fact that has been capable of withstanding serious criticism indicates that the net or resultant flow seaward of water from the most congested parts of the harbor is small and not to be depended upon as a means of carrying the sewage of New York promptly to the open sea. The water oscillates under the tidal influences in such manner as to cause the sewage substances which are discharged into the Harlem, Lower East river and some other parts of the harbor to remain for long and indefinite periods. The disposal of the sewage, in so far as it disappears, is ascribable chiefly to natural assimilative processes which the Commission has described in its reports under the general title of Digestion.

SECTION III

CORRESPONDENCE RELATING TO PROBABLE STABILITY OF AN ARTIFICIAL ISLAND

When, during the course of the Commission's investigations, the opinion was reached that it would be desirable to carry a large quantity of sewage, estimated at about 200 million gallons per day, from the territory naturally tributary to the Lower East river out of that part of the harbor and discharge it at sea, the question of a suitable site for the outlet became of much interest. There were comparatively few points in the ocean close to it where the necessary island for the outfall works could be constructed. After considerable study, the Commission decided tentatively upon two alternate sites and submitted these positions to the Survey, with a request for an opinion as to the probable effect which the waves and currents in the vicinity might be expected to have upon the structure. The Commission's letter to the Survey, dated November 27, 1912, describes the island proposed and the two alternative sites. The letter, which is marked Exhibit X, here follows:

EXHIBIT X

New York, November 27, 1912.

O. H. Tittmann, Esq., Director,
U. S. Coast & Geodetic Survey,
Washington, D. C.

Dear Sir: We beg to ask you for information concerning the permanency of the natural configuration of Lower New York bay. This inquiry arises from projects being considered by this Commission for the location of a sewer outfall of large size on a sand reef near the 14-foot channel.

We would like to know whether an island, say 50 acres in extent, would be permanent, if constructed of sand enclosed within a rip-rap wall about 250 feet at bottom and 60 feet at top, the whole to be raised to a height of about 18 feet above low tide. The location would be north of the 14-foot channel, a little east of a line between the Sandy Hook beacon and Coney Island light.

We have supposed this location would be favorable to stability in spite of the heavy waves which might be expected from the ocean in some severe storms. The reef which is south and east of the point indicated should, we suppose, protect the structure to a considerable extent.

Questions which we think should be considered in this connection are the velocity of currents and the movement of sand along the bottom under present conditions and under conditions which would occur after the island was constructed. The sewage would be discharged after treatment for the removal of impurities and should not be expected to produce deposits or materially alter the force and direction of the currents of tidal water in the vicinity, although the volume of sewage would be large.

Very sincerely,
George A. Soper,
President.

Under date of March 31, 1913, the Survey transmitted certain material which relates to the inquiries contained in Exhibit X. Exhibit XI contains the Survey's reply. It deals with the subject of currents, flow of water and winds in the Lower bay and with wave action, the movement of suspended matter, principles of breakwater design and with the probable permanency of the proposed structure. A large amount of material in tabular form relating chiefly to winds at the site of the island over a period of many years has been omitted from the exhibit because of the space required and as not indispensable to an understanding of the essential matters involved.

EXHIBIT XI

March 31, 1913.

Matters Relating to the Permanency of the Natural Configuration of Lower New York Bay and the Stability of an Artificial Island.

CURRENTS AT ENTRANCE TO LOWER NEW YORK BAY

The tidal currents over considerable portions of Sandy Hook bay, Raritan bay, Lower New York bay and Jamaica bay turn from flood to ebb or ebb to flood nearly simultaneously. Locations of comparatively early currents are, East coast of Sandy Hook, West coast of Sandy Hook, and Gravesend bay. The localities southwest, west and northwest from Coney Island light have comparatively late currents. Between Elm Tree beacon and Great Kills the currents are weak and do not turn simultaneously.

Between Sandy Hook and Coney Island the ordinary maximum velocity seldom reaches two knots per hour. These currents, although not strong, have an important influence upon the channels and shoals.

For a map showing the times of maximum flood velocity in Lower New York bay and vicinity, see Fig. 12, opposite p. 256, Coast and Geodetic Survey Report for 1907.

The accompanying table shows the results of current observations made in the vicinity of Fourteen Foot Channel and the accompanying blue print* shows their location.

Proofs that between Coney Island and Sandy Hook the sand is moved by currents:

1. The directions of the shoals and of the natural channels agree better with the directions of the current than with the direction of the prevailing wind.

2. The currents here are sufficiently strong for driving sand along the bottom; that is, they exceed 0.4 knot at the times of ordinary maxima.

3. The shoals and channels are here better differentiated than further eastward.

The unusual depth in Rockaway Inlet is maintained by the action of the tidal current. The shoal to the west of this inlet is caused by the fact that the flood stream north of the western end of Rockaway Beach flows easterly, while the flood stream south of Coney Island flows westerly, the times of maximum velocity being nearly the same in the two localities. This necessitates a very small velocity between Rockaway Inlet and the eastern end of Coney Island.

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*Not reproduced.

TABLE CXI

Current Observations, New York Lower Bay

Table of Slack Waters and Mean Maximum Velocities

Station	Date of Observation	Length of Obser-vation	Slack Time	Time	Flood True Direction	Vel., knots	Slack Time	Time	Ebb True Direction	Vel., knots
		Days	h. m.	h. m.	Degrees		h. m.	h. m.	Degrees	
A*	August 11–12, 1885	1¼	L. W.+1 50	H. W.—2 00	N.50W.	0.5	H. W.+0 20	L. W.—2 00	S.60E.	1.0
B*	August 12, 1885	½	L. W.+1 30	H. W.—1 50	N.60W.	0.8	H. W.+0 50	L. W.—2 10	S.55E.	1.3
C*	August 11–13, 1885	1¾	L. W.+1 50	H. W.—1 40	N.46W.	0.6	H. W.+1 10	L. W.—1 30	S.70E.	0.7
D**	October 2, 1877	¼	L. W.—0 25	H. W.—2 45	——	0.9	H. W.+1 35	——	——	——
E*	September 21–22, 1881	½	L. W.—0 20	L. W.+2 30	N.40W.	0.4	H. W.—0 00	H. W.+2 15	S.84E.	0.3
F*	July 18, 27, 1887	¾	——	H. W.—2 40	N.76W.	1.2	H. W.+0 22	L. W.—2 30	S.73E.	1.4
G*	May 9–10, 1889	1	L. W.+0 55	H. W.—2 05	N.69W.	1.1	H. W.+1 45	L. W.—1 50	S.71E.	1.2
H*	July 18, 27, 1887	1	L. W.+1 20	H. W.—2 30	N.75W.	1.1	H. W.+1 00	L. W.—1 35	S.66E.	1.6
I*	July 14–15, 1887	⅔	L. W.+1 10	H. W.—2 25	W.	1.5	H. W.+0 35	L. W.—1 55	S.67E.	1.8
J*	May 9–11, 1889	2½	L. W.+0 24	H. W.—2 40	N.84W.	2.0	H. W.+1 28	L. W.—2 22	S.83E.	1.8
K*	July 18, 28, 1887	1⅔	L. W.+1 30	H. W.—2 12	N.72W.	1.3	H. W.+1 00	L. W.—1 40	S.58E.	1.8
L*	August 12, 1858	½	——	H. W.—2 06	S.78W.	1.2	——	L. W.—2 10	N.73E.	0.8
M*	July 13–14, 1887	1	L. W.+1 00	H. W.—2 05	N.69W.	1.6	H. W.+1 15	L. W.—1 05	S.50E.	1.6
N*	August 28, 1858	½	——	H. W.—2 14	N.74W.	1.7	——	L. W.—2 10	N.81E.	1.6
O*	August 29–30, 1885	1	L. W.+1 05	H. W.—2 30	N.75W.	1.2	H. W.+1 10	L. W.—1 30	S.73E.	1.6
P*	June 20, 24, 1887	1	L. W.+1 08	H. W.—2 35	N.75W.	1.3	H. W.+1 02	L. W.—1 22	S.78E.	1.6
Q*	June 21, 24, 1887	⅔	L. W.+1 30	——	——	——	H. W.+1 00	L. W.—1 25	S.49E.	1.4
R*	August 17, 1858	¼	——	H. W.—2 50	N.69W.	1.6	——	L. W.—1 23	S.64E.	1.1
S*	May 10–11, 1889	1	L. W.+0 18	H. W.—1 55	N.77W.	1.9	H. W.+1 45	L. W.—2 25	S.71E.	1.7
T*	June 29, July 28, 1887	2	L. W.+2 00	H. W.—1 45	N.60W.	1.5	H. W.+1 25	L. W.—1 10	S.50E.	1.6
U*	August 30, September 12, 1881	½	——	H. W.—1 30	N.64W.	0.9	H. W.+1 10	L. W.—2 00	S.50E.	1.3
V*	July 1, 30, 1887	1	L. W.+1 18	H. W.—2 00	N.50W.	1.6	H. W.+1 05	L. W.—1 05	S.50E.	1.5
W**	August 13, 1855	½	L. W.+0 39	H. W.—2 29	N.51W.	0.7	H. W.+0 58	L. W.—2 21	S.58E.	1.4
X*	August 4–13, 1858	9	——	H. W.—0 23	N. 8W.	0.9	——	L. W.—0 03	S. 9E.	2.0
Y*	August 15–18, 1858	3	——	H. W.+0 06	N.12E.	1.5	——	L. W.+0 22	S.10E.	2.0
Z*	August 18–20, 1858	2	——	H. W.+0 41	N.20E.	1.1	——	L. W.+0 39	S. 9E.	1.8
AA**	August 12, 1855	½	L. W.+2 07	H. W.—1 00	N. 9E.	1.0	H. W.+2 02	L. W.—0 33	S.16W.	2.5
BB*	August 28–29, 1885	1	H. W.—2 45	H. W.—1 25	N.28W.	1.0	H. W.+1 00	L. W.+0 40	S.	1.7

*H. W. and L. W. are referred to high water and low water at Sandy Hook.

**H. W. and L. W. are referred to high water and low water at Governor's island.

RATE OF INFLUX INTO LOWER BAY, NEW YORK

The area here considered extends from a line joining the north angle of the fort upon Sandy Hook (about 830 feet east of Hook beacon) and "Continental Tower,"* Coney Island, westward to sections at the Narrows, Tottenville, Sayreville and Shrewsbury river entrance.

SANDY HOOK SECTION

The rate of influx across the Sandy Hook section was found by considering 16 partial sections, each 2325.2 feet in length, whose average depths were known and for which the current velocities were estimated from observations taken in the localities of each partial section.

For a very broad section like that extending from Sandy Hook to Coney Island, mean velocities may be derived from surface velocities (or from velocities measured by floats extending well down into the water) by multiplying by the factor 0.9.† Moreover, since on an average the streams do not cross the section exactly normally but 13° from a normal a further factor of cos 13° or 0.97437 has to be applied.

The half-tide level depths and the velocities as ascertained from near-by observations are as follows, beginning at the Coney Island end:

No.	Depth, feet	Velocity, knots	Product
1	11	0.8	8.8
2	23	1.6	36.8
3	15	1.3	19.5
4	12	1.2	14.4
5	17	1.2	20.4
6	18	1.4	25.2
7	24	1.5	36.0
8	17	1.7	28.9
9	32	1.9	60.8
10	20	1.3	26.0
11	15	1.3	19.5
12	26	1.4	36.4
13	24	1.3	31.2
14	27	1.2	32.4
15	47	1.6	75.2
16	12	1.5	18.0
			489.5

This sum multiplied by 1.689 (the factor to convert velocities expressed in knots per hour into velocities expressed in feet per second), then by 2325.2 (the width of each partial section) and by 0.9 (the empirical factor to reduce to mean velocity) and by .97437 (because the flow is not exactly normal to the section), gives

$$489.5 \times 1.689 \times 2325.2 \times 0.9 \times .97437 = 1{,}685{,}812$$

cubic feet per second which cross this section at the time of strength of flood or ebb. This multiplied by 14,233 gives 23,944,162,000 cubic feet as the tidal volume passing the section on a flood or ebb period of 6 lunar hours.

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*Should be "Centennial Tower." E. F. R.

†Encyclopædia Britannica, Vol. 12, pp. 509, 510.
Darcy and Bazin: Recherches Hydrauliques (Atlas), Plates 19–23.
Merriman: A Treatise on Hydraulics, 4th Ed., Art. 113.
Bovey: A Treatise on Hydraulics, 2d Ed., p. 259.
Murphy: Accuracy of Stream Measurements, Water-Supply and Irrigation Paper No. 95, p. 138.

TABLE CXII

NEW YORK HARBOR, N. Y.

COMPUTATION OF FLOOD AND EBB VOLUMES, INCLUDING NON-TIDAL DISCHARGES

	(1)	(2)	(6)	(7)	(8)	(9)	Total flood volume (10)	(11)	Total ebb volume (12)
	A	C	$A\sqrt{1\frac{C^2}{A^2}}$	$\cos^{-1}\left(\frac{C}{A}\right)$	$C\cos^{-1}\left(\frac{C}{A}\right)$	(6) – (8)	(9) × 14233	(2) × 44714	(10) + (11)
			Section between Sandy Hook and Coney Island.						
January...	1685812	22281	1685660	1.5576	34705	1650955	23498043000	996256000	24494299000
February..	“	17449	1685711	1.5604	27227	1658484	23605203000	780200000	24385403000
March.....	“	63159	1684632	1.5333	96842	1587790	22599015000	2824058000	25423073000
April......	“	65444	1684531	1.5320	100260	1584271	22548929000	2926258000	25475187000
May.....	“	33829	1685475	1.5507	52459	1633016	23242717000	1512638000	24755355000
June......	“	27476	1685593	1.5545	42711	1642882	23283140000	1228568000	24511708000
July.......	“	17624	1685728	1.5604	27500	1658228	23601559000	788054000	24389613000
August....	“	15734	1685745	1.5615	24569	1661176	23643518000	703564000	24347082000
September.	“	17895	1685711	1.5602	37920	1657791	23595339000	800174000	24395513000
October....	“	24894	1685626	1.5560	28735	1646891	23440200000	1113116000	24553316000
November.	“	23035	1685643	1.5571	35868	1649775	23481248000	1029990000	24511238000
December..	“	29621	1685559	1.5532	46007	1639552	23335744000	1324452000	24660196000
Mean.....	“	29870	1685542	1.5531	46391	1639151	23330036000 *23322888000	1335556000	24665592000 *24658499000

WINDS

The accompanying tables and diagram† show the results of wind observations taken hourly on Ambrose Channel light vessel, No. 87, Lat. 40° 28′ (02″), Long. 70° 50′ (01″) from November 5, 1912, to February 3, 1913. The velocities are expressed in statute miles per hour, and the directions are magnetic. On the diagram the heavy lines represent velocities in magnitude and in direction, the letters in the circumference of the circle showing the point of the compass from which the wind blows. The distance from the center of the diagram to the frequency curve represents, when scaled off according to the scale on the diagram, the number of days in the observation period of 91 days (24-hour periods), during which the wind was blowing from the direction specified in the circumference of the circle.

The maximum velocity for each principal direction, as recorded during this period of 91 days, is given at the end of the table of hourly observations.

The general direction of the wind for New York, Setauket and Asbury Park, taken from Prof. A. J. Henry's Climatology of the United States is given in a separate table. It is probable that the Weather Bureau could furnish much additional information at these three places should it be wanted.

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*These values are the average for the flood and ebb volumes for the 12 months.

A = rate of maximum tidal flow through given cross-section (cubic feet per second).

C = rate of run-off (cubic feet per second).

Total flood volume = 14233 × $\left\{A\sqrt{1\frac{C^2}{A^2}} - C\cos^{-1}(C/A)\quad.\right\}$

“ ebb “ = 14233 × { “ “ “ “ } + 44714 C.

The angle whose cosine is C/A is expressed in radians.

†Not reproduced.

TABLE CXIII

Prevailing Winds

From Henry's Climatology of the United States.
Monthly, Seasonal and Annual Means.

Month	New York, N. Y. Lat. 40° 43′ N. Long. 74° 00′ W. Direction of prevailing wind	Setauket, N. Y. Lat. 40° 57′ N. Long. 73° 05′ W. Direction of prevailing wind	Asbury Park, N. J. Lat. 40° 13′ N. Long. 74° 00′ W. Direction of prevailing wind
December	NW.	W.	NW.
January	NW.	W.	NW.
February	NW.	W.	NW.
Winter Mean	NW.	W.	NW.
March	NW.	W.	NW.
April	NW.	W.	SE.
May	NW.	W.	SE.
Spring Mean	NW.	W.	SE.
June	SW.	W.	SE.
July	SW.	S.	SE.
August	NW.	S.	SE.
Summer Mean	SW.	S.	SE.
September	NW.	S.	NE.
October	NW.	NW.	NE.
November	NW.	W.	NW.
Fall Mean	NW.	NW.	NE.
Annual Mean	NW.	W.	NW. SE.

The Direction of Wave Travel

While we have no observations on this subject, the directions taken by Sandy Hook, Coney Island and Rockaway Beach show that the waves which produce the greatest littoral drift of sand or gravel are from the direction of the open ocean, notwithstanding the fact that the prevailing winds are westerly.

For the three months during which winds were observed at Ambrose Channel light vessel (Nov., 1912, to Feb., 1913) there occurred no heavy easterly gale.

Depth to Which Wave Action Extends

Wave action sufficient for preventing the rapid deposition of matter in suspension may extend to considerable depths, possibly to the hundred-fathom line.*

Wave action sufficient for agitating sand may extend to a depth of 75 to 90 feet. It is said that, off Nantucket Shoals where the depths are as above, sand is "frequently left on deck by a sea which has broken on board."†

For Lake Superior the deposition of sand upon piers and breakwaters indicates a wave agitation down to 30 feet or more.‡

"At the harbor of refuge, Milwaukee Bay, Wis., it was found as a result of one winter's experience that the limit of wave disturbance for half-ton stones was about 13 feet below the water surface, and for stones of 250 pounds more than 20 feet, the depth of the water being about 30 to 35 feet." §

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*Vaughan Cornish: Waves of the Sea and Other Water Waves, Ch. V.

†Capt. D. D. Gaillard: Wave Action in Relation to Engineering Structures, p. 138.

‡Ibid., p. 142. §Ibid., p. 140.

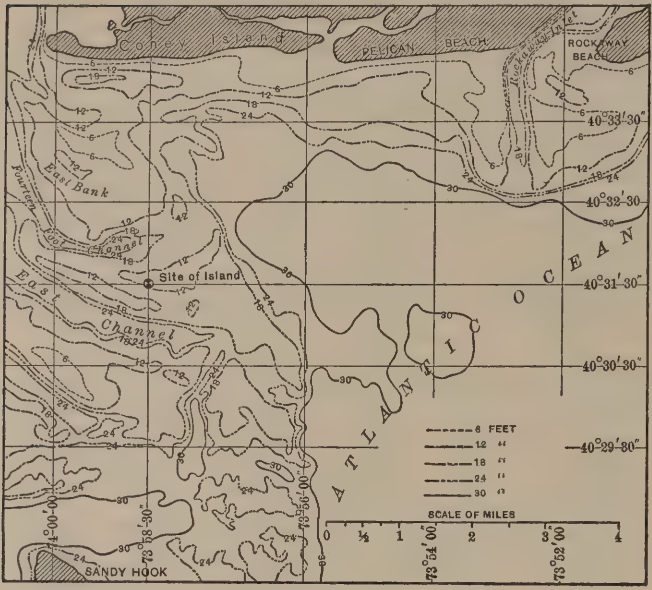

FIG. 31—1844

DEPTH AT WHICH WAVES BREAK

Waves coming from deeper water usually break when the undisturbed depth is reduced to about the height of the wave from trough to crest. The ratio depth ÷ height is generally somewhat greater than unity. For an on-shore wind this ratio is greater than for an off-shore wind.

The following are a few references to this subject:

Capt. D. D. Gaillard: Wave Action in Relation to Engineering Structures, Ch. VII.

Vaughan Cornish: Waves of the Sea and Other Water Waves (English Edition, 1910), pp. 166-175.

W. H. Wheeler: A Practical Manual of Tides and Waves, pp. 122-124.

COASTLINE AND DEPTH CHANGES

The following are a few references to matter which relates to changes in coastline and depth in Lower New York bay and vicinity:

General for Lower Bay

Appendix No. 11, Report for 1895 gives a list of original topographic and hydrographic sheets. These sheets can be consulted at this office.

Various editions of Chart No. 369, particularly the editions of 1844-45, 1857, 1874, 1889, 1905, and latest edition 1912. See the accompanying photastat copies.* The plane of reference used in the 1844-45 edition was about low water springs; this plane as then determined at Sandy Hook was 0.8 foot lower than the plane of mean low water.

Rockaway Inlet

Report of the Jamaica Bay Improvement Commission (1907), Plates I and II.

Sandy Hook

Coast Survey Report, 1854, Sketch 93.

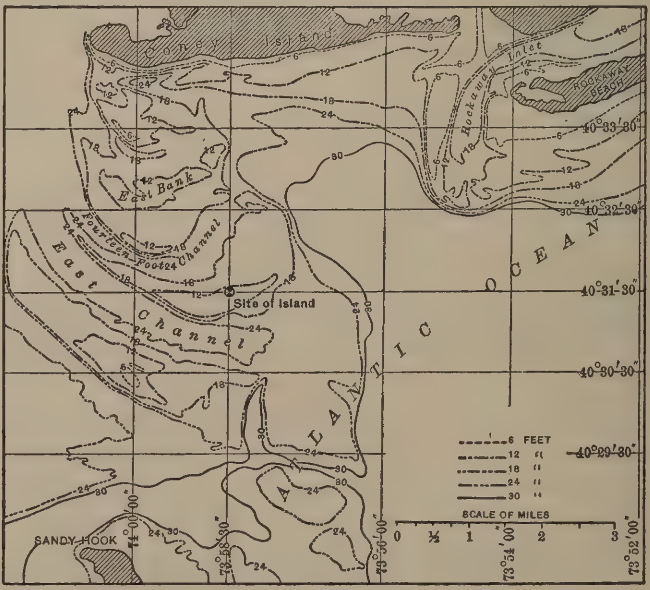

FIG. 32—1874

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*See Figs. 31-35.

Coast Survey Report, 1856, pp. 263-4.

Coast Survey Report, 1873, Sketch, p. 110.

Lt. C. H. Davis: A memoir upon the geological action of the tidal and other currents of the ocean, text and Plate 3. Mem. of the Am. Acad. of Arts and Sci., Vol. IV (1849).

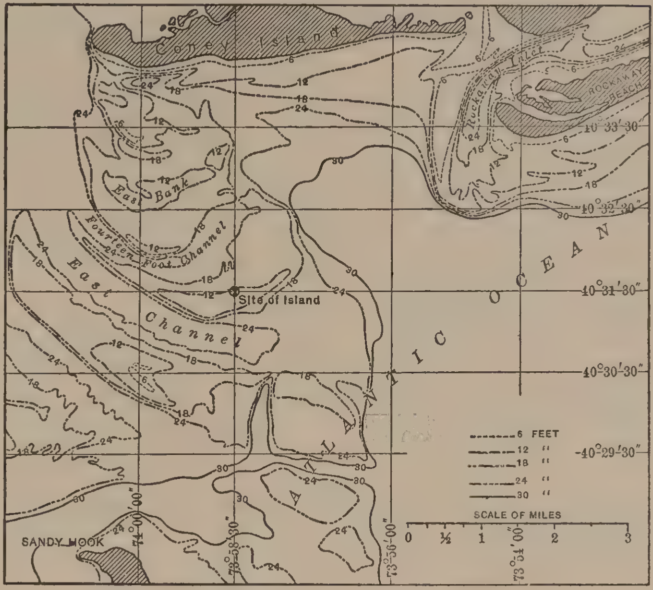

FIG. 33—1889

Matter in Suspension

From the table giving the flood and ebb discharge across the Sandy Hook to Coney Island section, it can be readily inferred that matter in suspension will be gradually carried seaward unless deposition should occur. This is prevented by the wave agitation common to this and similar localities. That such matter is not extensively or permanently deposited can be seen from the character of the bottom, which in no case is marked upon the charts as being covered with a layer of mud.

Further inland where the waters are more protected, as in Raritan Bay and near the coast of Staten Island, the bottom is more or less muddy.

Accumulation of Sand at the Ends of the Island

The effect of an obstruction like the proposed island upon the deposition or rather the accumulation of matter is somewhat problematic.

It is reasonable to suppose that sand will accumulate at both the inner and outer (*i. e.*, westerly and easterly) ends of the island whichever of the two suggested positions may be chosen, but that the tendency to accumulate will be greater at the inner end than at the outer. The accumulation would probably be less for the position near the Fourteen Foot Channel than for the position further east, because of the rather swift currents occurring in this channel.

That sand will accumulate at the inner (western) and outer (eastern) ends of the island, there is probably no doubt. The amount will be greater at the inner end than at the outer, because the latter is more exposed to wave action.

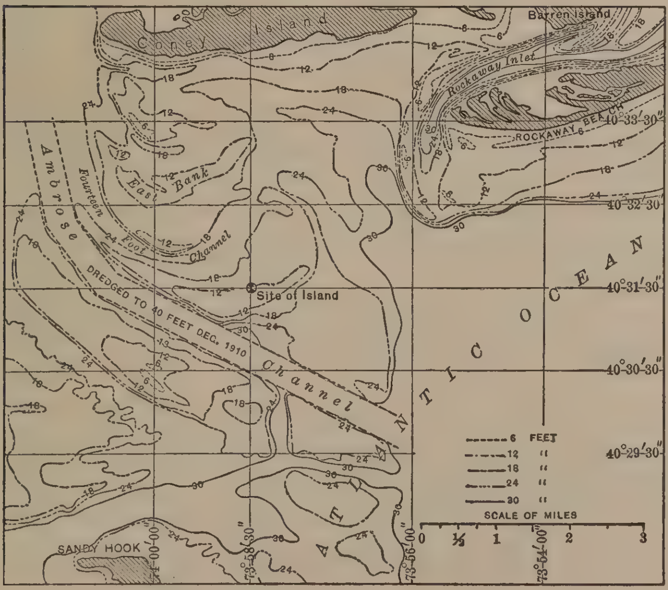

FIG. 34—1912

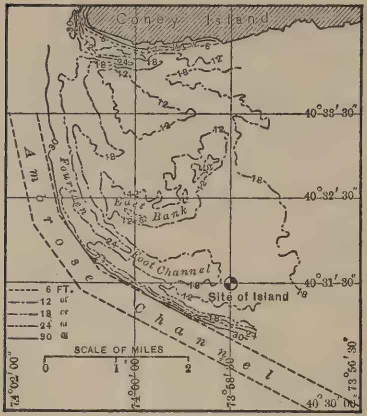

FIG. 35—1913

In fact, during such storms as may give rise to violent wave action, a considerable portion of the sand accumulation at the exposed end of the island may be removed. How far below the low water line such action may leave the wall of the island free from sand is uncertain.

The currents in the Fourteen Foot Channel are of sufficient strength for dissipating any accumulation of sand which may tend to take place at points within their reach.

The following references may be of some interest in connection with this topic:

Vaughan Cornish: Waves of the Sea and Other Water Waves (1910), Ch. V.

Lt. C. H. Davis: Memoir upon the Geological Action of Tidal and Other Currents of the Ocean. Mem. Am. Acad. Arts and Sci. Vol. IV (1849).

Suggestions Concerning the Location of the Island

The more westerly of the two indicated locations has the advantage of being protected by a stretch of shallow water lying southeastward of Fourteen Foot Channel. This, acting as a submerged breakwater, will greatly reduce the size of the waves. On the other hand, the proximity to Fourteen Foot Channel is objectionable because the tendency of the currents in this channel, taken in connection with the wash of the waves, might be to undermine the mound or wall surrounding the island unless the foundations were carried down to a depth of about 35 feet below mean low water, or the depth of the channel. By placing the island further from this channel, say a distance equivalent to the indicated width of the island, there seems to be no reason why this objection would not be overcome in a satisfactory manner. A comparison of the soundings at and near the point whose position according to a recent chart is 40° 32′ N. and 74° 00′ W., indicates that the northern edge of this channel has moved southward rather than northward since the surveys underlying the 1844 edition of chart No. 369 were made. The longitudes on this chart are reckoned from the City Hall, New York. On recent editions of this chart, a depth of 36 feet below mean low water occurs near the above-mentioned point. On the 1844 edition the greatest depth shown is 30 feet below low water springs, which in this case signifies about 31 feet below mean low water. In other words, the channel has near this point become deeper by 5 feet. (It may be noted that the 1844 edition shows a patch marked "Dry at low water" lying about one nautical mile north of this point. Recent editions show the least depth to be 3 feet below mean low water.)

The principal objection to the more easterly one of the two suggested locations is, of course, the exposure to wave action from the southeast.

Breakwater Designing

The following are a few references to breakwater designing and similar matters:

Brysson Cunningham: A Treatise on the Principles and Practice of Harbour Engineering, Ch. VI. London, 1908.

Thomas Stevenson: The Design and Construction of Harbors, Ch. VI. Edinburgh, 1886.

De Cordemoy: Ports Maritimes, Ch. XXXI. Paris, 1908.

Law and Burnell: The Rudiments of Civil Engineering, Ch. VII. London, 1882.

Thomas Stevenson in Ency. Brit., 9th Ed. Article "Harbours."

International Engineering Congress, 1904. Trans. Am. Soc. of Civil Engineers, Vol. 54, Part A (1905). Papers Nos. 6-15 and discussion, pp. 137-451. In particular, Paper No. 12, Harbors on Lakes Erie and Ontario; Paper No. 13, Harbors on Lake Superior, particularly Duluth-Superior Harbor; Paper No. 14, Seacoast Harbors in the United States; Paper No. 15, The Delaware, Sandy Bay and San Pedro Breakwaters.

Louis Y. Schermerhorn: Breakwater Construction of the American Coast. Proceedings of the Engineers' Club of Philadelphia, Vol. 14 (1897), pp. 205-228.

Emil Low: The Breakwater at Buffalo, N. Y. Trans. Am. Soc. of Civil Engineers, Vol. 52 (1904), pp. 73-214.

The Sandy Bay Breakwater, National Harbor of Refuge, Cape Ann, Mass. Eng. News, Vol. 55 (1906), pp. 258, 259.

Proposed Improvements of the Southwest Pass at the Mouth of the Mississippi. Eng. News, Vol. 43 (1900), pp. 117, 118.

William Starling: The Improvement of the South Pass of the Mississippi River. Eng. News, Vol. 44 (1900), pp. 121-125.

William Starling: The Projected Improvement of the Southwest Pass. Eng. News, Vol. 44 (1900), pp. 222-229.

Examination and Survey of St. Johns River, Florida. House of Representatives, Doc. No. 611, 61st Cong., 2d Session.

Maj. J. C. Post: Improvement of Willamette and Lower Columbia Rivers and Their Tributaries. Ann. Report of the Chief of Engineers, U. S. Army, 1895, Pt. 5, App. UU, pp. 3551-3608.

B. S. White: Breakwaters and Plans for Breakwater Extension at Agate Bay, Two Harbors, Minn. Journal of the Association of Engineering Societies, Vol. 28 (1902), pp. 171-194.

Max E. Schmidt: The South Pass Jetties. Transactions of the American Society of Civil Engineers, Vol. VIII (1879), pp. 189-226.

Permanency of a Proposed Island

The island in question is supposed to contain about 50 acres, to be constructed of sand enclosed within a riprap wall about 250 feet wide at the bottom and 60 feet at the top; and to reach a height about 18 feet above low water. Its location is supposed to be one of the two shown upon the accompanying blue-print.*

Of course, it may be said in advance that the stability will depend upon the size of the blocks of stone constituting the riprap and upon what slopes are given to the outer or water faces of the wall or mound. Both of these items, and especially the first, would have to be more definitely specified before any positive answer could be given.

The depths at and near the proposed location of the island are generally less than 16 feet, and so there is no doubt about wave agitation extending to the bottom at times when the waves coming in from the ocean reach considerable size. Because the depth of water is considerably less than the lengths of such waves, these do, in a measure, lose the character of deep-water waves and begin to resemble long waves or waves whose horizontal motion is alike from top to bottom. Consequently, there is no plane or depth of "rest," say 15 feet below mean low water. Such a plane is often found convenient in breakwater design where the depths are greater than those now under consideration. Between this plane and low water the slope of the seaward-face is frequently taken as about 1 on 3; below this plane the rubble mound may be built to a steeper slope, thus leading to an economy of material. In the present case it would seem to be best to have the same slope, say, 1 on 3 or 1 on 2½, from low water level down to the bottom. Moreover, the slope should be faced all the way down with rather large revetment stones. Those used in the Buffalo breakwater weighed about 6¼ tons each.*

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*Not reproduced.

There seems to be no reason why the slope of the interior face may not be quite steep, say, 1 on 1, or 1 on 1½, from the bottom up to mean low water. Above this plane the slope might be even steeper than 1 on 1.

On the outer or exterior face, the greatest effect of wave action would doubtless occur at and above the low water level. From this plane up to the top of the structure, the steepness is usually greatly increased, thus making a saving of material. At the same time, stones of comparatively large dimensions are required in order to withstand wave action. Too great steepening, however, would cause an increase in wave action on the riprap wall just below the line where such increase in steepness begins. For in the case of a sea-wall built upon a rubble mound, it has been found that the rubble near the wall is rapidly worn away by the waves.†

The breakwaters at Buffalo,‡ National Harbor of Refuge in Delaware Bay,§ and at Sandy Bay,‖ seem to constitute the best examples for the case under consideration.

The works of Cunningham, Stevenson, Law and Burnell, and Gaillard already mentioned by title, give numerous illustrations of the destructive effects of waves upon structures composed wholly or partially of rubble work.

A profile of the jetty at the mouth of the Columbia River shows the amount of rock washed away from October to December, 1893.¶

The following quotations are added as having an important bearing upon this mode of construction.

"The disturbing influence of waves is most keenly felt between the levels of high and low water, and it is in this region that the most trying ordeals of a breakwater are experienced. A difficulty underlying the situation is that in proportion as the slope is flattened to maintain its equilibrium, the disruptive effort of the wave is fostered and increased. Hence the introduction of huge blocks and monoliths to withstand impact. These blocks, which rarely weigh less than 25 or 30 tons apiece, and often considerably more, may be deposited either in courses or at random. In the former case, they may be stepped so as to form a general inclination of 1 to 1; but if deposited at random, a flatter slope will be necessary.

"The blocks, when artificial, are generally made in the form of rectangular solids; parallelopipeds in preference to cubes; and they should be laid as headers—that is,

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*Emile Low, l. c., p. 133.
†Law and Burnell, l. c., pp. 392, 393 and 397.
‡Emile Low, l. c.
§Louis Y. Schermerhorn, l. c., p. 219.
International Engineering Congress, 1904, Paper No. 15.
‖Engineering News, Vol. 55 (1906), pp. 258, 259.
Louis Y. Schermerhorn, l. c., p. 213.
International Engineering Congress, 1904, Paper No. 15.
¶Maj. J. C. Post, l. c., opp. p. 3560.
See also Paper No. 14, p. 316, International Engineering Congress.

with their ends facing the line of wave action. In this way the minimum face area is exposed to the stroke, and there is the maximum resistance to overturning.

"Natural blocks are heavier per unit volume than the majority of artificial blocks, and, for this reason, have claims to preference. They are also less liable to disintegration, but they are difficult to procure economically to large dimensions, and their irregular shapes render it impossible to bed them systematically. They have a tendency, also, towards becoming rounded like boulders, and this does not improve their steadiness *in situ*."*

"Breakwaters built of rubble, although expensive in upkeep, are suitable for very sheltered sites in shallow water, provided good and cheap material is procurable. This type is not affected by the muddy or soft nature of the sea bottom.

"When the structure is exposed to very heavy seas, the rubble type of mole can still be adopted, under the conditions mentioned above, provided a revetment of concrete blocks is added outside down to a certain depth. The method of depositing these blocks at random appears the best as regards resistance and maintenance, on condition that the profile of the protected slope is so designed that it will shear the waves at sea-level. On the other hand, the method of setting the blocks in regular courses offers serious objections, as they are liable to be disturbed by the settlement of the rubble base and to be completely destroyed during gales, and, in any case, they cannot be maintained in good condition without abandoning the principle of the system itself.

"Breakwaters with a rubble hearting and a double revetment of protecting blocks, laid in regular courses, are not at all reliable in very heavy seas, but they can render very useful service in sheltered sites and in waters of moderate depth, especially if the works are not of very great importance.

"Breakwaters with vertical, or almost vertical sides, are very suitable for moderate depths and hard sea-beds, where there is no fear of the undermining effect of the backwash and currents. They are very expensive and consequently inapplicable to unimportant works.

"The composite type of breakwater, consisting of a base formed by a loose rubble mound, surmounted by a vertical superstructure, is peculiarly suitable for tidal seas and for seas with a slight tidal rise and fall, provided the water in that case be very deep. In the case of tidal seas, there is no objection to stopping the superstructure at low water level.†

"A very obvious and very important point regarding the stability of such a structure as a breakwater has reference to the depth below low water at which the waves cease to exert any considerable impact upon the materials on which the superstructure rests. It was found at Wick that the very anomalous waves which assailed that work did not disturb any of the rubble base at a lower depth than 18 feet under low water. I am therefore of opinion that a level of from 18 to 20 feet below low water may be safely assumed as that of practical stability. I conceive that the safest and most economic profile of construction is, as is shown in Fig. 15, a mass consisting of large rubble extending to within 20 feet of low water; when the base has been brought up to this level, blocks of concrete, weighing from 100 to 200 tons, should be deposited on the top and outer or seaward surface of the rubble base, till they come above low-water level. Betwixt the spaces, at the top of these blocks, bags of concrete should be placed so as to form a level platform above low-water level. Upon this a solid mass of concrete *in situ,* should extend from end to end of the breakwater, which should not be less than 10 feet above high water, and about 45 feet in breadth. A structure designed on these principles will, I think, be found able to resist the force of the sea in any situation, provided the sea slope be of sufficient extent. The design shown in Fig. 15 is that proposed by Messrs. Stevenson for the harbor of refuge at Peterhead.

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*Cunningham, l. c., pp. 136, 137.

†Quoted by Cunningham, l. c., pp. 140, 141.

"*Level of Conservation of Rubble.*—If we further keep in view that any settlement of the foundation is far more perilous to a vertical than to a sloping wall, there seems good ground for believing that the ordinary method of forming the low-water parts of deep harbors of large masses of rubble stone or of concrete blocks, is, in most circumstances, the best and cheapest kind of construction when a vertical wall is to adopted. Loose rubble or blocks of concrete, after being acted upon by the waves, are less liable to sink, or to be underwashed, than when a vertical wall is founded upon a soft bottom. Loose concrete blocks above low water form an excellent protection to the upright wall. Two precautions should, however, be kept in view: *First,* the wall should be founded at a sufficiently low level to prevent underwashing. A depth of from 12 to 15 feet under low water was pointed out by the late Mr. J. M. Rendel as the level below which the waves did little or no damage to *pierres perdues.* Sir John Rennie indeed considered that there was little or no effect at a fathom and a half.* No works executed at an earlier date than those at Wick had been founded at a lower level than 12 feet; but at Pulteneytown, where the rubble is more exposed than at any other harbor, Messrs. Stevenson, as already stated, considered it advisable to found the wall 18 feet below low water, and the rubble was moved down to 18, and at Alderney to 20, feet below low water. *Secondly,* in all cases where the structure is to act simply as a breakwater, and not as a pier, there should be no parapet, the want of which relieves the foundation, as was observed by Mr. D. Stevenson at a harbor work where a breach had been made."†

"Jetties entirely in loose rubble work are principally constructed for the purpose of destroying the force of the waves without its being intended to make them serve for the purpose of assisting the maneuvers of vessels entering or departing. Such a mode of construction may be advisable when the rough materials are easily procured, and when skilled labor is exorbitantly dear; but, as a general rule, it will be found that the ultimate expense of the maintenance of such works will more than counterbalance any economy in the original outlay."‡

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*Min. Civ. Eng., Vol. VI, p. 122.

†Thomas Stevenson, l. c., pp. 98–100.

‡Law and Burnell, l. c., pp. 425, 426.

CHAPTER VI

DIGESTION OF SEWAGE BY THE HARBOR WATER AND THE EXHAUSTION OF DISSOLVED OXYGEN, WITH TABLES OF OXYGEN AND OTHER CHEMICAL RESULTS

SECTION I

ANALYTICAL WORK RELATING TO NEW YORK HARBOR

In the present chapter the principal analytical work done by the Commission in its studies of New York harbor and not hitherto published, is described. Upon the reorganization of the Commission in 1908 a compilation was made of all the analytical data available up to that time concerning the condition of the harbor waters, and a summary of the results was published by the Commission under the title of "Digest of Data Collected Before the Year 1908 Relating to the Sanitary Condition of New York Harbor." The most extensive part of the data contained in the digest represented the work done by the New York Bay Pollution Commission in 1904 and 1906. Bacterial and chemical analyses were made by the Pollution Commission and had been published in that Commission's report to the Governor of the State of New York, March 31, 1905, and April 30, 1906. The total number of samples analyzed was about 165.

The Digest of Data described the investigations made by the Metropolitan Sewerage Commission in 1907, these including the only analytical results made by this Commission until 1909. The results included determinations of numbers of bacteria in the water and in solid matter at the bottom of the harbor, presumptive tests for the colon bacillus and results of chemical analyses of the water. There were 755 samples of water in which the numbers of bacteria were determined. There were 705 samples of solid matter analyzed for bacteria and 322 presumptive tests made. There were 47 samples analyzed for ammonia. Other chemical tests included free and albuminoid ammonia, chlorine and loss on ignition. Color and turbidity tests were made on about 900 samples.

The Digest described brief investigations made by the Department of Water Supply, Gas and Electricity in 1904 and 1905 to determine points along the water front at which to locate intakes for the auxiliary fire service. In these studies, 383 samples were collected and analyzed for numbers of bacteria, B. coli, free ammonia, albuminoid ammonia, nitrites, nitrates and chlorine.

Investigations of the water of the Lower Hudson river were made in 1903 by Whipple in connection with studies for an additional drinking water supply for the City of New York. The data collected which were capable of showing the sanitary condition of New York harbor was small. The results were discussed in the Digest issued by the Sewerage Commission.

Finally, the Digest contained a summary of the investigations of the condition of the Passaic river conducted by Hazen and Whipple in 1906. This report was restricted in scope and contained little information relating to New York harbor.

A large part of the analytical work done by the Metropolitan Sewerage Commission since 1908 has been performed with the oxygen test. The method of making this test and the results obtained have been described in the Commission's reports, always, however, with the form of apparatus originally employed. The method with the apparatus used up to May, 1912, is best shown in the report of the Commission for August, 1912, Part III, Chapter III, pp. 298-306. The old apparatus is shown in Fig. 85, p. 305, of the report cited. The new apparatus, known as the Soper Oxygen Bottle, from having been devised by the President of the Commission, is shown in Fig. 36 of this report.

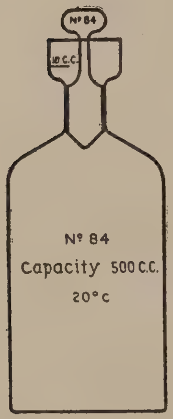

FIG. 36

Soper Oxygen Bottle

This apparatus consists of a bottle, usually of about 500 c.c. capacity, with a long funnel-shaped lip. A stopper which is convex at the bottom fits accurately into the neck and when in place permits about 15 c.c. of liquid to stand in the funnel without overflowing. The capacity of the bottle is accurately determined with the stopper in place.

In use the bottle is filled to the beginning of the funnel with the water to be examined and the stopper is set down in place. The excess of water which rises in the funnel is poured off. The stopper is removed and to the bottle of about 500 c.c. capacity, 6 c.c. of a standard solution of ferrous sulphate are delivered by a pipette to the bottom of the bottle where it remains unless the bottle is agitated. The stopper is replaced and the water which rises in the funnel is poured off. Five c.c. of sodium carbonate solution (200 grams per liter of water) are then poured into the funnel. The stopper is cautiously raised sufficiently to allow the heavy alkali to sink through the water to the bottom of the bottle, where the reaction producing a heavy precipitate begins. The stopper is set back in place, the water in the funnel is poured off and the bottle is shaken until the free oxygen is entirely absorbed. Ten c.c. of a 50 per cent. solution of sulphuric acid is poured into the funnel and the stopper raised sufficiently to permit the heavy acid to diffuse, discoloring and permitting the contents of the bottle to be titrated. Finally, the contents are poured into an Erlenmeyer flask and titrated with permanganate of potash, each c.c. of which represents 1 c.c. of oxygen.

A blank determination is made whenever the water contains much organic matter or sodium chloride. The same steps are followed in making the blank as in making the analysis except that the sodium carbonate is omitted. The difference between the permanganate required by the blank and that absorbed in the actual analysis represents the dissolved oxygen present.

The purpose of this apparatus is to permit of the addition of reagents to the bottle without exposing the contents to the air.

The reagents used are as follows:

Standard Ferrous Sulphate. This is prepared by dissolving 144 grams of Kahlbaum's crystallized ferrous sulphate in water, adding 15 cubic centimeters of concentrated sulphuric acid and diluting the whole to 3 liters.

Standard Sodium Carbonate. Prepared by dissolving 200 grams of sodium carbonate crystals in 1 liter of water.

Standard Sulphuric Acid. Prepared by mixing equal parts of concentrated sulphuric acid and water.

Standard Potassium Permanganate. Prepared by dissolving 25.4 grams of potassium permanganate in water and diluting to 4.5 liters. This reagent is standardized against especially prepared Mohr's salt.

The total number of oxygen analyses made from 1909 to 1914, inclusive, was approximately 3,710.

The Commission's report of August, 1912, contains tabulations, maps and diagrams showing the oxygen and other analytical work done up to the time that report went to press. In addition to the oxygen, the results of bacterial analyses and microscopic examinations were recorded.

The present volume describes the oxygen results obtained by the Commission subsequent to those recorded in the 1912 report. The same method of tabulation has been preserved and the diagrams and other representations which were introduced in 1912 have been followed in plotting the data wherever this method of record seemed likely to aid in comparing and comprehending the facts.

No bacterial or microscopic analyses were made by the Commission after those recorded in the 1912 report.

A feature of the analytical work done toward the end of the Commission's existence was the making of chemical examinations of the kind customarily employed in standard sanitary investigations, the object being to afford a check upon the oxygen work and obtain data concerning the behavior of the nitrogen compounds. These chemical examinations included analyses for free and albuminoid ammonia, nitrites and nitrates.

Before making the nitrate examinations, considerable time was spent in comparing methods for this test. The presence of salt in the sea water so interfered with the customary nitrate analysis as to require that special provision be made for overcoming the difficulties.

After some preliminary investigation, it was decided to test the two most promising methods for the electrolytic reduction of nitrates to the form of ammonia and the subsequent estimation of the ammonia in the usual way. The reduction procedures which were compared were the copper zinc method, as described by McGowan (See Part V, Vol. IV, Fourth Report Royal Commission on Sewage Disposal of Great Britain) and the aluminum foil method, as recommended by the Committee on Standard Methods of Water Analysis of the American Public Health Association. Parallel tests were made with these, using sea water, harbor water and land water. Definite weights of sodium nitrate were added and the increases noted by analysis.

The results of the research show that nitrates were present in all the samples and that nitrates in sea water and mixtures of sea water and land water can be reliably determined by either of the reduction methods tested. The data obtained in these experiments follow:

TABLE CXIV

AMOUNT OF NITROGEN FOUND, AS NITRATE IN LAND, HARBOR AND SEA WATER, BY REDUCTION—(a) WITH ALUMINUM FOIL, AND (b) WITH COPPER ZINC COUPLE

Source of Sample	Parts per 1,000,000	
	Series A Aluminum Reduction	Series B Copper Zinc Reduction
Land Water	0.004,0	0.366,0
" "	0.291,0	0.300,0
Harbor Water	0.425,0	0.445,0
" "	0.520,0	0.560,0
Sea Water	0.240,0	0.260,0
" "	0.160,0	0.160,0
" "	0.100,0	0.180,0

TABLE CXV

AMOUNT OF NITROGEN FOUND, AS NITRATE IN LAND AND SEA WATER CHARGED WITH KNOWN QUANTITIES OF KNO_3, BY REDUCTION—(a) WITH ALUMINUM FOIL, AND (b) WITH COPPER ZINC COUPLE

Source of Sample	Present Theoretically	Parts per 1,000,000	
		Series A Aluminum Reduction	Series B Copper Zinc Reduction
Land Water	0.005,2	0.005,0	0.005,0
Sea Water	0.138,0	0.127,0	0.131,0
" "	0.011,0	0.010,0	0.010,0
" "	0.005,5	0.005,0	0.004,5
" "	0.005,5	0.005,1	0.006,0
" "	0.010,0	0.010,0	0.007,5
" "	0.016,5	0.015,0	0.016,5
" "	0.035,0	0.033,0	0.035,0

As a consequence of this research, the Commission employed the reduction method for the determination of nitrates throughout its subsequent work. The chemical examinations are fully stated in the tables following the oxygen results here given.

In connection with the oxygen and other analyses of the harbor water, it sometimes became desirable to make incubation tests and these, in properly tabulated form, are appended to the oxygen results which are stated in the following tables.

The data here published are capable of yielding many interesting and important facts relating to the harbor's condition and particularly to the phenomena concerned in the digestion of the sewage. The information of principal value is believed to have been extracted during the course of the work, but it is not improbable that further careful study of the details would repay the care and time expended.

Since the Commission was reorganized in 1908, all the analytical data, in common with all the other scientific and technical facts have been collated and tabulated as the work progressed.

The Commission considers that its analytical work has been sufficiently thorough and comprehensive to afford the information needed for definite opinions concerning the condition of the harbor and the method which should be followed for its improvement. It would be desirable to repeat some of the investigations from year to year to show what changes, if any, occur. The system which should be followed in these studies has been made clear by the work which has been done.

Excepting for the study of detailed conditions in certain localities and the investigation of special problems, it will be sufficient to take samples at the principal cross-sections established by the Commission and made a feature of its final work. The analyses need not be either numerous or elaborate. The determinations of dissolved oxygen as described in this Commission's reports will probably afford all the information necessary. It is essential that the method of analysis should be the same or at least that a test should be followed which is as free from error as that which the Commission has employed, otherwise the results will not be strictly comparable. The utmost pains were taken by the Commission in selecting and testing the accuracy of its dissolved oxygen method and the fullest confidence may be placed in this test.

SECTION II

DIGESTION OF SEWAGE BY THE HARBOR WATER AND THE EXHAUSTION OF DISSOLVED OXYGEN

DIGESTION OF SEWAGE IN NEW YORK HARBOR

From an early period in its career, the Commission has given attention to the conditions under which sewage matters would disappear when discharged into the harbor waters. The conditions required for assimilation, collectively termed the "phenomena of digestion," were made the subject of experimental investigation in the laboratory and in the open harbor water, and were among the profitable directions in which these researches were carried.

The point toward which the Commission was working in these experimental and analytical studies was an understanding of the circumstances under which the greatest use could be made of the harbor for the reception of the sewage without injurious consequences to the public health and welfare. The need of utilizing the harbor's digestive capacity was apparent. It was evident that engineering works capable of carrying the sewage to a distant point for disposal, or plans for its intensive treatment, would be very expensive. Since a sanitary disposal of the sewage was to be looked upon as a necessity and not as a luxury, it was necessary to confine the construction to the most economical works which would answer the actual requirements.

Pollutions from the docks and shipping would always add a considerable amount of sewage matters, even though the most extensive works were built to keep the land sewage from entering the harbor. It was recognized that the harbor was capable of assimilating large quantities of sewage materials and experience here, as well as at other points known and visited by the Commissioners, pointed to the possibility of making large use of the harbor's digestive capacity for sewage. Obviously certain conditions which produced nuisance and injury to health would have to be prevented. If the harbor was to be used for the reception of a large part of the sewage, it would be necessary to make a scientific use of the natural forces by which the objectionable matters could be disposed of.

It was explained in the Commission's report of 1910 that freedom from evil consequences attending the discharge of sewage and other wastes into New York harbor depended upon the bodily transportation of a part of the refuse matters from the harbor to sea by means of the harbor currents and the assimilation of the remainder by the water itself. Owing to the backward and forward oscillation of the tide, the seaward transportation is irregular and the amount of upland water poured into the harbor by the rivers is insufficient to carry the sewage wastes promptly away. The ultimate disposal of the wastes depends largely upon the assimilative capacity which the Commission has termed "digestion."

The Commission's first report, dated April 30, 1910, contained an account of the bacterial condition of the harbor waters and several chapters deal with the phenomena and assimilation or digestion of sewage matters. The relative intensity of pollution was shown not only by bacterial studies, but by analyses of the dissolved oxygen made in all the important sections into which the harbor was divided. The deposits upon the harbor bottom were studied with reference to the intensity of their pollution; and in Chapter X there was given a discussion of the diffusion and digestion of sewage in the harbor, in which information was furnished on the composition of the polluted wastes and the results of experimental studies on diffusion and digestion carried out by means of laboratory tests, the discharge of large volumes of sewage into the harbor and investigations on the floatation of solid objects.

In Chapter X of the 1910 report the solids of sewage were discussed under the heads of those which sink, those which float, and those which remain suspended in the main body of the water into which they are discharged. The liquid portion of the sewage was considered under the headings of oil and grease and the liquids which are principally concerned with the depletion of oxygen.

The Commission's report of August, 1912, contains a further discussion on the phenomena of digestion in Chapters V and VI of Part I, and of the state of the water as shown by the dissolved oxygen, bacteria and microscopic debris in Chapters VII and VIII.

A thorough account of some of the principal phenomena of digestion, especially as they relate to the depletion of oxygen, was contained in the report of Prof. W. E. Adeney who was brought to America from England by the Commission for the purpose of consultation upon this topic. Professor Adeney's report with respect to the degree of cleanness which is sufficient for the water is contained, like the reports of seven other eminent experts selected by the Commission, in Chapter III, Part II, of the 1912 report.

All the data and opinions on the question of the digestion of sewage and the part which oxygen plays in this phenomenon are not to be found in the references there given. For example, a large part of the 1912 report (over 150 pages) is devoted to the dissolved oxygen question, and all of Part III, excepting that which is devoted to the oxygen, relates to the microscopic examinations and numbers of bacteria. Scattered through the preliminary reports of the Commission will be found other mention of this important topic.

Composition and Quantity of the Sewage

The term "sewage" has been used by the Commission to mean the wastes which flow from dwelling houses, factories and streets through the municipal sewerage systems and these wastes after discharge, whether solid or liquid, are usually referred to as sewage materials.

The composition of the sewage represents a theoretical standard which has been assumed for New York. The aggregate quantity of sewage materials discharged in 1910 was equivalent to 255,000 tons of dry, solid matter, all of which was capable of offensive putrefaction, or already advanced to some extent toward that condition. One ton of this material was equivalent to about 50 tons or 55 cubic yards of wet sludge, such as is deposited on the harbor bottom and as is ordinarily obtained from sedimentation basins. It thus appears that there is discharged each year into the harbor of New York sewage sufficient to produce 12,800,000 tons of sludge, having a bulk of 14,000,000 cubic yards.

The Suspended Matters.—Fresh sewage taken from the New York sewers has a dirty, gray color and an unpleasant, sweetish, musty odor. It contains particles of solid matters whose identity is readily recognizable to sight, and finer particles which collectively produce a turbid appearance in the liquid. Most of the solid particles will pass through screens having meshes of one-eighth of an inch. Such screens as are used in the purification of sewage upon a practical scale are capable of removing, say, 15 per cent. of the suspended matter, this removal being slightly greater or considerably less, depending upon the fineness of the screens employed. About one-third of the suspended matter removed by screens consists of paper and other material which is not readily susceptible to decomposition.

A considerable proportion of the finer material is in a semi-solid colloid condition, which causes the purification of sewage to be attended with particular difficulty.

Upon standing, some of the particles settle out causing a dirty grayish or blackish sludge to deposit.

Under usual conditions about 60 per cent. of the total solids in sewage are in suspension, and about one-half of these can be removed by allowing the sewage to flow very slowly through sedimentation tanks during a period of about two hours. It is estimated that about one-half of the resulting sludge consists of organic matter capable of putrefaction. By adding a chemical precipitant before the sewage is settled, about 85 per cent. of the suspended matter, and 50 per cent. of the organic matter can be removed as sludge.

The putrefiable material in the sewage is by some believed to be largely in the sludge, but experiments made by this Commission show that the liquid part of sewage, when preserved for a few days in bottles, will use up the contained oxygen and produce the characteristic odors which may be expected from raw sewage when preserved under the same conditions. There is as much organic matter in solution as in suspension in the sewage produced by the average city, but the fresher the sewage, the larger the relative amount of organic matter in suspension and the smaller the relative amount in solution.

Of the total amount of organic matter present in solid or suspended form, about one-half is nitrogenous. Fats and soaps are sparingly present in spite of appearances to the contrary.

The Commission in its first report divided the solids of sewage into those which sink soon after the sewage is discharged into the harbor; second, those which continue to float for some time on the surface of the water; and, third, those which are long carried in suspension in the body of the tidal streams. Many which at first float gradually become broken up or water-soaked and sink beneath the surface of the water, thus passing from the second to the first division or to the third.

Turbidity Due to Sewage Discharges.—The water of the harbor is markedly discolored and rendered turbid where the sewers discharge. The size of the materials which produce the turbid appearance varies from sub-microscopic particles up to masses whose identity can immediately be distinguished from the docks and vessels in the vicinity. The water, which is generally of an olive, slightly turbid appearance, becomes brownish gray, greasy and muddy in appearance. The boundaries of the sewage stream are for some time sharply defined in the surrounding water. When the harbor currents are sufficient to carry the sewage promptly away from the outfall, the discolored area expands and fades from sight.

The discharge of sewage is generally not recognized, except for the grease and larger particles, beyond a distance of two or three hundred feet. In some cases, as, for example, the mouth of the Harlem river and those bends in the Lower East river known as Wallabout bay and the foot of Oliver street, Manhattan, the sewage discolors many acres of the harbor.

Sludge Deposits

Most of the deposits which exist on the harbor bottom consist of colloid and other finely divided particles. Accumulations of this material are difficult to handle except by pumping. When dredged, much of it flows back into the water. Sea water has a tendency to precipitate finely divided solid matters, and large areas of New York harbor are covered with deposits; in fact, the only parts of the harbor which are not contaminated by sewage solids are those wherein the tidal currents are too swift to permit deposits of any kind to form.

About 350,000 cubic yards of material are dredged from the waterways around Manhattan Island by the Dock Department of the city and a large amount of additional dredging is done at private expense. Unfortuntely, the deposition of sludge cannot be regulated so as to take place at certain points from which they may be easily dredged. The accumulations which occur near the mouths of the sewers are being continually moved from place to place by the changing currents, which set the semi-solid sewage particles in motion.

Sewage sludge which remains for a time upon the bottom gradually undergoes a change in which the more solid materials are disintegrated and turned into liquid and gaseous compounds, some of which have a strong avidity for oxygen. It is after the sewage solids have been deposited upon the harbor bottom and decomposition has set in that putrefactive changes become most pronounced, and the most offensive odors are given off.

The Docks as Sewage Traps.—The more quiet parts of the harbor, and especially the spaces between the long docks, are of much interest from the standpoint of oxygen exhaustion. They have been well termed "sewage traps." The study which anyone can make of them from the surrounding piers and bulkheads will make it clear why the slips continually require to be dredged in order that a proper depth of water may be preserved for navigation; why the water bubbles with offensive gases; why the dredged material is so foul and why it is that sewage solids accumulate between the piers even when the bottoms of the main tidal currents beyond the pierhead line are relatively free from sewage deposits. Knowledge of these localities, based on personal inspection, will make it easy to understand why the extension of the sewer outfalls in Manhattan from the bulkhead lines to the ends of the docks has not produced satisfactory conditions, and why something more is needed in the way of protecting the water than would be afforded by passing the sewage through screens or settling basins in the crowded and polluted sections of the Lower East river.

Precipitating Action of the Salt Water.—Experiments made by the Commission show that sewage deposits take place more rapidly in New York harbor water than in the water of inland rivers and lakes. Two bottles, alike in all respects, were filled, in one case, with harbor water and, in the other, with water from the public drinking water supply. An equal quantity of sewage sludge was placed in each bottle. The bottles were thoroughly shaken and allowed to stand upon a table to permit the deposit to settle out. At the end of half an hour the harbor water was noticeably clearer than the upland water. At the end of one hour the difference was marked; a heavy deposit had settled upon the bottom of the harbor water and there was little change in the bottle containing the upland water. At the end of three hours some deposit was visible in the upland water, but the water itself was not as clear as the harbor has been at the end of the first half hour. As nearly as could be estimated, the harbor water deposited its suspended matter more than twelve times as rapidly as the upland water.

Conditions Necessary for Final Disposition

Elsewhere the Commission has shown that the final decomposition of sewage by natural processes requires that the solids shall be liquefied and the liquids oxidized. Nature requires that all organic matters be resolved into stable mineral forms. In this final condition, all substances are inoffensive and incapable of becoming so.

The liquid part of sewage contains about one-half of the total organic matter present, and, unlike the solid material, is in condition for immediate oxidation. The oil and grease which sewage contains, although not large in amount, change slowly in composition, but their effects, when discharged into the harbor waters, are conspicuous. The grease floats upon the surface of the water, at times, in large patches which are distinctly visible for 1,000 feet or more from the mouths of the principal sewer outlets. A distinctly greasy odor is imparted to the shores.

The chemical changes, and particluarly the absorption of oxygen, which occur during digestion of sewage in water has been investigated by Adeney and made the subject of an exhaustive report to the Royal Commission on Sewage Disposal of Great Britain.* The work of this investigator was based on the well-known researches of Frankland, which showed that the essential cause of change was one of oxidation, and those of Dupré, who proved that the rate of oxidation was largely due to bacteria.

It appears that the digestion of sewage matters in water depends not alone on the exact quantity and chemical composition of the sewage, but rather upon the fermentative properties of the mixture of sewage and water. The rate at which sewage matters undergo change depends largely upon the influence of the organisms present. Adeney was convinced that the purification of polluted sea water was chiefly a physiological process analogous to the respiratory process of higher vegetable organisms, and that enzymic action was intimately associated with the process.

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*See Appendix VI, Fifth Report of the Royal Commission on Sewage Disposal, 1908.

The Two Stages in the Self-Purification of Sewage Polluted Water.—In a report made by Professor Adeney to the Metropolitan Sewerage Commission,* an explanation is given of the fermentative processes which sewage undergoes through the action of water bacteria, from which it would appear that decomposition proceeds in two distinct and progressive stages: The organic matters are first completely fermented and are almost entirely oxidized during the process; the products are water, carbon and ammonia. Small quantities of organic substances appear as excretory bodies which result from this process, and these possess the chemical and physical properties of the humus of cultivated soils, peated rivers and lakes.

When the fermentation of the organic constituents has been completed the second stage occurs during which the ammonia compounds and humus matters formed during the first process are oxidized to nitrites, nitrates, carbon dioxide and water. The terms "carbon fermentation" and "nitrogen fermentation" are suggested as descriptive of these two stages of sewage fermentation in water, and the following classification of the bodies which may occur in polluted waters is recommended:

1. Carbon fermentable substances, that is, nearly all existing organic substances other than antiseptics which have not to be subjected to the fermentative action of water bacteria.

2. Nitrogen fermentable organic substances, that is, organic substances which have resulted from the carbon fermentation of other organic bodies.

2a. Ammonium Compounds. It is to be observed that the oxidation of organic carbon to carbon dioxide constitutes the central feature of the first stage, and that the oxidation of ammoniacal nitrogen to nitrous and nitric acid constitutes the central feature of the second stage.

The products of the second stage are the analogues of the product, carbon dioxide, of the first stage. The sequence of these changes is in conformity with thermo chemical principles, and an exposition of the scientific basis upon which this view of the self-purification of polluted waters is founded is contained in Section 1, Appendix 6, Fifth Report of the Royal Commission on Sewage Disposal.

According to Professor Adeney's reasoning, the most important effect produced by the introduction of sewage into the harbor waters, and one which invariably follows, is the more or less complete exhaustion of their dissolved oxygen. Three distinct causes of loss are to be noted:

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*See Report of Metropolitan Sewerage Commission, August, 1912, pp. 80–121.

1. The sewage being deficient in oxygen would, by mere physical pollution, lower the amount of dissolved oxygen in any mixture of sewage and clean water which might be made with it.

2. Where sewage contains substances which should easily, directly and immediately oxidize, without the intervention of bacterial or enzymic action.

3. The organic and ammonium compounds of sewage when acted upon by fermentative processes cause a loss of the dissolved oxygen. Ordinarily only the last of these three actions is capable of producing appreciable influence upon the dissolved oxygen in the water.

The first is instantaneous in effect; the second may be practically instantaneous, as where sulphuretted hydrogen and black sulphite of iron, both of which are among the most commonly occurring bodies of a directly oxidizable character found in sewage sludge, especially in the presence of sea water, are oxidized by direct contact with dissolved oxygen with great rapidity.

The effect of the third action upon the dissolved oxygen is distinctly different since it proceeds with extreme slowness, and occupies several days under natural conditions. The effects which the sewage sludge matters discharged into New York harbor exert, when they become diffused through the tidal waters after having been deposited in the form of sludge, subjected there to putrefactive processes in the presence of sea water, and finally raised by gas, eddies or other means and diffused, are much more injurious than those which the same solid matters can cause when in a fresh condition. The explanation of this fact lies in the large quantities of sulphides and other immediately oxidizable compounds which are produced in the fermenting sludge.

Liquid sewage matters when discharged in a fresh condition are not, for the most part, capable of direct chemical oxidation, but must await the fermentative action of bacteria.

AMOUNT OF OXYGEN PRESENT IN UNPOLLUTED WATERS

The quantity of dissolved oxygen which is present in unpolluted water under ordinary circumstances is relatively small. The utmost which can be present, termed the saturation value, varies according to the salinity of the water and the temperature.

Other things being equal, sea water contains less oxygen than water that is not salt. Harbor water containing 45 per cent. of sea water holds, at 45 degrees F., 7 c.c.

of oxygen per liter of water. When the temperature reaches 75 degrees the oxygen is expelled to the atmospheric air until about 5.5 c.c. are present. During the summer months the water may become so warm, particularly in those parts of the harbor in which a free circulation does not occur, as to reduce the normal amount of oxygen to about 5 c.c. per liter.

The physical law by which the amount of oxygen which can be present is reduced in warm weather operates against the disposal of New York's sewage by dilution, since, at the season when decomposition is most active and oxygen is most in demand, the supply of it is most deficient.

The difference in the amount of oxygen which may be present in sea water and upland water amounts to 20 per cent. under summer conditions. Thus, at 70 degrees F., the saturation value of oxygen is 5.2 c.c. per liter in sea water and 6.4 in upland water. The table on page 52 and the diagram on page 51 of the Commission's report of August, 1912, give the amount of oxygen required to saturate tidal waters containing various percentages of sea water and mixtures thereof under different conditions of temperature.

Method of Stating Results.—Throughout the work of the Commission, it has been customary to state the amount of oxygen present as cubic centimeters of oxygen per liter of water and as percentages of saturation value. This custom is followed by the Royal Commission on Sewage Disposal of Great Britain, but in America the results are stated as parts of oxygen by weight per million parts by weight of water. The Commission's method of stating the results can be converted into parts per million by multiplying the number of cubic centimeters found by 1.43. The diagram on page 51 of the Commission's report of August, 1912, facilitates this conversion.

SOURCES OF THE DISSOLVED OXYGEN

The dissolved oxygen which is present in a natural body of water is assumed to have been derived from the atmosphere. Numerous analyses of the Hudson river, Long Island sound and ocean beyond the limits of sewage pollution show that an amount of oxygen is present which compares closely with the theoretical saturation value, and were it not for human occupancy the water of New York harbor would doubtless contain the maximum supply which the temperature and salinity of the water permit.

There are various sources from which the oxygen which is exhausted by the sewage substances is in part replaced. Among these sources are the atmosphere, the fresh water which enters the harbor from the ocean, sound and rivers and the oxygen which exists in combined form in the mineral matters which the harbor waters contain.

Absorption of Oxygen from the Air.—The absorption of oxygen from the atmosphere has been the subject of scientific controversy, Professor Adeney holding views upon this subject which Professor Phelps and Colonel Black have attacked. It is unnecessary here to enter into the scientific details, many of which can be found in Appendix VI of the Fifth Report of the Royal Commission on Sewage Disposal of Great Britain; in Professor Adeney's report to the Commission, published in the Commission's report of August, 1912; in the report of Colonel William M. Black and Professor Earle B. Phelps to the Board of Estimate and Apportionment of New York in 1911; and in a paper and discussion opened by Professor Phelps in the Proceedings of the American Society of Civil Engineers in 1913. The chief point at issue seems to lie in the interpretation of the results of certain delicate experiments which the authors have made to determine the exact way in which the oxygen is absorbed by harbor water and transmitted from the surface downward.

Among the admitted conditions upon which absorption of oxygen or, as it is sometimes called, reaeration, proceeds are the area of water exposed to the air, the temperature of the water, the salinity of the water, the humidity of the atmosphere, the amount of oxygen which the water already contains, the depth of the water, the rate at which the oxygen which is absorbed at the surface may be diffused throughout the body of the water and the presence or absence of vertical currents.

Owing to the variation which occurs in all of these factors in New York harbor, it is apparent that the rate at which oxygen is absorbed from the air varies greatly from day to day, hour to hour and place to place. The area of the water surface changes continually under the influence of the winds which produce waves and sometimes break the surface. Decided temperature changes occur under the influence of the sun and inflowing waters. The salinity changes with each tide and with the rainfall. The humidity of the atmosphere, and, consequently, the evaporation from the surface of the water, correspond with changes in the weather. The amount of oxygen present in the water is by no means the same throughout the harbor, nor does it remain constant in any place which is under the immediate influence of the sewage and the tidal currents. The depth of water varies as the currents flow through the shallower and deeper channels. The rate of diffusion under these changing conditions cannot be expected to follow any fixed law, but, if it does so, the effects must be greatly modified by the lateral and vertical currents set up by the tide and by the large amount of traffic in the harbor.

The rate at which absorption of oxygen can take place under any circumstances is relatively slow. In the year 1912, the Commission made a series of experiments on the absorption of oxygen by water and the results obtained, and stated elsewhere in this report, show the approximate rate at which oxygen is absorbed by water from the air. In these experiments, sea water, land water and mixtures of the two were deprived of more or less of their oxygen by boiling, cooled without allowing air to come in contact with them and then exposed to the atmosphere for various periods of time, the dissolved oxygen being determined before and after the exposure.

It was found that water absolutely or nearly free from oxygen, if exposed to the air in an open vessel, such as a wide-mouthed bottle, will, without any agitation of the surface, at first absorb oxygen rapidly from the atmosphere, the rate decreasing as the degree of saturation increases until, as the saturation figure is approached, the process of absorption goes on slowly. In the experiments, water nearly devoid of oxygen absorbed over 50 per cent. of the saturation value of oxygen in the first 24 hours, the rate for the first hour being 10 per cent. of the total quantity necessary for saturation. The rate during the second day was about 25 per cent. of that of the first day. The rate then decreased gradually during the third and fourth days, when there was a marked falling off, so that at the end of the week, as the saturation value was approached, the absorption amounted to a very little each day.

The rate for sea water was rather more rapid than for land water. While the land water absorbed 53 per cent. or slightly more during the first 24 hours, the sea water absorbed 60. After the second day, the rate of absorption was greater in the land water than in the sea water, an observation which is doubtless to be accounted for by the fact that the sea water was more nearly approaching its saturation value.

In no case was the water found to be saturated at the end of seven days, although it closely approached that condition. It took ten days in some cases before the land and sea waters became fully saturated.

The gain during the first hour of exposure was about the same with land water as with sea water. At the end of the 2d, 3d, 4th, 5th, 6th, 7th, 8th and 24th hours, the absorption of oxygen was found to be greater with the sea water than with the land water, the total gain for the first day with the sea water being about 8 per cent. greater.

In mixtures of sea water and land water possessing from 14 to 45 per cent. of oxygen, the gain per hour varied between 10 and 4 per cent. If these facts are applicable to New York harbor, it would appear that the absorption of oxygen from the atmosphere under conditions such as are likely to occur in the summer weather is equivalent to about 7 per cent. of the saturation value per hour. The conditions, however, under which the oxygen can be absorbed by the harbor waters are too numerous to make deductions of this kind entirely safe.

Fresh Sea Water and Upland Water as Sources of Oxygen.—In the opinion of many persons, direct absorption from the atmosphere plays but a small part in supplying the oxygen required by the harbor for the digestion of the sewage. The principal supply is furnished by the fresh sea water and relatively unpolluted river water which enter the harbor.

Calculations have been made of the extent to which the water of the sea and rivers renews the water of the harbor, the object of these calculations being to determine the extent to which the sewage matters are carried mechanically to sea. So far as the ocean water is concerned, the basis of these studies has been the estimates of the United States Coast and Geodetic Survey made in 1908 at the request of the Metropolitan Sewerage Commission; the Commission's studies of the changing salinity of the water carried on throughout one year at 11 widely separated stations in the harbor; the float observations and the thousands of analyses made in the Commission's laboratories. The supply of water from the rivers has been calculated from runoff data supplied by the New York State Engineer. Mathematical discussions of the transportation of the sewage to sea have been made by Professor Adeney, Messrs. Black and Phelps and others without, however, affording convincing evidence of the practical application of the results. The inward and outward flow of sea water, like the discharge of water from the rivers, does not produce the immediate and thorough diffusion throughout the harbor waters which such calculations assume.

Oxygen Supplied by Mineral Compounds.—In most waters a considerable amount of oxygen is present in the form of mineral compounds, as, for example, carbonates, sulphates, nitrates and nitrites. These compounds are relatively stable and some of them may be regarded as the end products of those changes which organic matters undergo in the process of decomposition in the presence of oxygen. This is particularly true of nitrates. Nitrates are always abundant in waters which have been polluted and in which digestion has passed to its final and inoffensive state.

Carbonates indicate a water possessing temporary hardness and are usually taken as showing the solution of rocks containing lime and magnesia in the presence of carbonic acid, presumably derived from the decomposition of vegetable matter as in swamps.

Sulphates indicate a permanently hard water, that is one whose soap-consuming and boiler-scale-forming properties are not reduced by boiling. Sea water contains a great deal of sulphate, a considerable amount of carbonate and very little nitrate.

When sewage matters putrefy in the presence of sea water, the oxygen present in the form of mineral compounds is attacked, the result being a reduction in the nitrates and sulphates if not in the carbonates present. The Commission has found that nitrates are reduced before the dissolved oxygen is entirely gone from the water and putrefaction commences. There is thus little, if any, oxygen to be depended upon from nitrates after the dissolved oxygen is gone.

The sulphates do not readily part with their oxygen. They are among the most resistant of chemical substances and are broken down only in the presence of active putrefactive decomposition, so far as sewage is concerned.

Analysis of the gases evolved from New York harbor shows very little sulphuretted hydrogen and a great deal of marsh gas and other compounds from which sulphur is absent.

It is doubtful whether the carbonates in harbor water are capable of affording any useful amount of oxygen in the mineralization of the sewage matters. Putrefaction produces carbonic acid, much of which goes into solution in the water and some of which is evolved in bubbles at the surface.

A brief consideration of the changes which take place in the nitrogen compounds will serve to indicate, in a general way, how the oxygen may be combined with the elements of the sewage as a result of digestion and how it may be disrupted from such combination.

Nitrogenous matter, in the least digested form in which it is customarily determined in sewage and water analysis, is reckoned as albuminoid ammonia. In this condition it is not ammonia, but is assumed to be in an albuminous condition which is capable of being converted into ammonia in nature by biological action or in the laboratory by means of strongly alkaline permanganate of potash. Theoretically, the nitrogen of albuminoid ammonia will, in course of time, become free ammonia and then pass to nitrites and nitrates. In the changes which result in free ammonia, oxygen is not known to play any part.

Once the nitrogen has reached the stage of ammonia, the presence of oxygen becomes an important factor. The nitrogen and hydrogen atoms, of which ammonia is composed, unite with oxygen and form nitrites which, by further oxidation, are converted to nitrates. The presence of nitrites in water is regarded as indicating the rate at which the digestive process is proceeding. Nitrites, when abundant, are generally accepted as indicating recent heavy pollution. Nitrates, when high, are taken to signify that the water has passed through a change which has resulted in the oxidation or mineralization of such harmful and offensive matters as may have been present. The proportion in which these various compounds, ranging from albuminoid ammonia to nitrates, are present in a water gives to the sanitary analyst a knowledge of the recentness and extent of the pollution of the water.

It has often been remarked that sea water contains but little nitrates, their presence having been questioned by some. The Commission has shown that sea water contains nitrates. In view of the enormous extent to which organic matter is diluted in sea water, it does not seem remarkable that only small quantities are discoverable.

Nitrites are present to an unusual extent in the water of New York harbor. Their presence well illustrates the digestive changes which are taking place. When considered in the light of other data relating to the quality of the water, there is little about their presence to cause remark.

In order that the Commission's investigations should have a broad foundation and not rest exclusively upon the extensive dissolved oxygen analysis which were made, a considerable number of analyses for the nitrogen compounds were carried out and the results will be found in appropriate places in the tables.

The circumstances and extent to which the oxygen which is present in the form of mineral compounds can be turned to the most useful account in the digestion of the sewage matters depend upon many factors which have nowhere, as yet, received thorough investigation. The discovery of the controlling factors in the problem will doubtless remain a field of research for many years to come. It now appears that before this combined oxygen can be liberated and made available for the digestive processes, putrefaction, or an approach to it, must intervene.

Attention has recently been attracted to the instrumentality of plankton in breaking up the completely or partly oxidized mineral compounds present in polluted water and thus adding to the dissolved oxygen content. The theory upon which the action of the plankton depends is the same as that which seeks to explain one of the most important of those facts relating to the inter-relation of animals and plants. In the respiratory action of animals, oxygen is absorbed and carbonic acid is evolved, and the corresponding function of plants is to appropriate the carbon and liberate the oxygen of carbonic acid.

However complete the action by which the oxygen that may be present in mineral combinations is liberated, it is evident that it can bring about nothing more than an exchange. No oxygen is produced. Nevertheless, the effect upon the digestive process may be excellent. It may facilitate decomposition, for the oxygen, when disassociated from the other elements with which it is combined, is present in a nascent form and in this state it undoubtedly has a strong avidity to form combinations.

Elsewhere in this report will be found the results of experiments on the disappearance of nitrates in water concurrently with the absorption of dissolved oxygen. The experiments show that the oxygen in the form of nitrates may be absorbed, to some extent at least, long before the dissolved oxygen disappears.

There is another source of oxygen which, although probably never available, is nevertheless of much interest in considering the digestion of sewage. This source is no other than the oxygen of which the water itself is composed. If, in the digestion of sewage, the molecules of water which are composed of two atoms of hydrogen to one of oxygen become disrupted and the oxygen set free, the digestive capacity of a river or harbor would obviously become enormously increased. In the existing state of knowledge, there is no reason to suppose that the oxygen of which water is composed is ever made available for the mineralization of organic or nitrogenous matter.

Oxygen as a Measure of Pollution

In the Commission's opinion the amount of dissolved oxygen which is present in a natural body of water affords the best means available for measuring the burden of pollution which has been put upon the water and gives a basis upon which to form an opinion as to the maximum quantity of sewage which the water can properly absorb. So far as future conditions are concerned, the test has reference chiefly to the possibility that the sewage materials in the water may putrefy and produce offensive odors. If there is much oxygen, this probability is remote; if there is but little, the danger is imminent. Putrefaction cannot take place in the presence of an abundant supply of oxygen.

The scientific value of the analysis depends on the fact that the oxygen which is normally present in the water is used up by the processes of nature in changing the decomposable substances of the sewage into harmless and inoffensive compounds. This change has been termed digestion. It is a complicated process and one which depends upon a large number of factors, including the amount and condition of the organic matter in the sewage and in the water; the amount of dissolved oxygen present in the mixture; the temperature of the water and the presence of various substances which may exert a beneficial or injurious effect upon the digestive process.

The water itself plays but an indifferent part in the digestive process. It acts in a mechanical way to separate the particles to be digested and so permits the active agencies of decomposition to come freely into contact with the substances upon which they must operate without undue interference from the harmful products of their activity. The active agencies which carry on the process of digestion include a wide range of animal and plant forms, among which the bacteria are prominent. The water may be likened to a laboratory in which the forces of nature attack and render the great variety of waste substances inert. When these wastes are too concentrated, that is, when they are not diluted with a sufficient supply of clean water, they pass through undesirable and offensive changes.

A question of much practical significance in the disposal of sewage through dilution is whether putrefaction has any effect upon the total quantity of oxygen which a given volume of sewage requires. It would seem that the laws of chemistry demand that a given amount of nitrogenous and organic matter require a definite quantity of oxygen for its final mineralization irrespective of any changes through which the materials requiring oxidation may pass. A consideration of those changes, however incomplete and imperfect as the existing knowledge of them is, shows that putrefaction may lead to a reduction in the quantity of oxygen needed. Putrefaction produces gases and with these gases there are driven into the atmosphere oxygen-demanding elements, notably carbon and hydrogen, which lessen, by their weight, the weight of oxygen which the water must supply.

Proof of the correctness of this theory has not been afforded by laboratory research, but a strong presumption in its favor is supplied by the composition of the gases and by the fact that most of the gases are inflammable. Viewed in this light, putrefaction may be regarded as the natural provision by which the oxygen requirements of decomposable organic and nitrogenous bodies, whether of sewage or other origin, may be lessened in natural bodies of water to a point which can properly be satisfied by the oxygen present.

The term organic matter is generally applied rather loosely to indicate the decomposable materials in water which require oxygen for their resolution into inert mineral compounds, whether these materials are of sewage origin or are derived from natural sources. It constitutes those chemical elements which are capable of putrefaction when decomposed in the absence of oxygen and those which abstract oxygen when decomposition proceeds under ordinary aerobic conditions.

From a chemical standpoint, organic matter is not necessarily of animal or vegetable origin. It can be produced synthetically, as urea and asparagin, for example. Organic chemistry is the chemistry of the carbon compounds and from a scientific standpoint it is proper to include as organic matter all, and only, those substances which include carbon atoms. If this definition is employed, there will remain outside, and in addition to those substances commonly called organic matters, an important class of compounds derivable from sewage which demand oxygen for their mineralization. These include ammonia and nitrites. In the reports of this Commission, the term organic matter is used in its usual and popular sense to include all sewage substances, which abstract oxygen from the water. In this way it is hoped that much confusion will be avoided.

Dissolved oxygen figures are not capable of giving a knowledge of the existence of fresh sewage odors. Such odors are often present when large quantities of sewage are discharged into natural bodies of water and before decomposition, either of the offensive or inoffensive kind, has set in. They are due largely to air entrained in the sewers which escapes after the sewage is discharged. Fields of sewage which lie on the surface of the harbor water about the sewer outfalls generally give off sweetish, greasy odors which are offensive and which bear no relation to the amount of dissolved oxygen which the water contains. Nor are these odors always confined to the immediate vicinity of sewer outfalls. The well-mixed water in the center of the Lower East river has often been observed to give them off. The smell is particularly noticeable in the wake of steamboats whose propellers were churning up the waters and sending a fine spray into the air. The amount of dissolved oxygen bears no known relation to the existence of the odors of fresh sewage produced in such cases.

The most important case in which the oxygen figures fail to indicate the existence or probability of odor is where relatively clean water flows over the top of sludge deposits. This is the most usual cause of the offensive odors which rise from sewage pollution. Sludge is concentrated sewage and when it becomes stagnant the oxygen is soon exhausted from it, putrefaction sets in and foul-smelling gas is evolved. The gas escapes sometimes in very large bubbles which rise through the overlying water and escape at the surface, its transit being relatively short. The gas has a strong avidity for oxygen and it may or may not materially affect the dissolved oxygen in the water through which it passes, according to the amount of gas, the depth of water through which it rises, the temperature and other conditions.

INSUFFICIENCY OF OXYGEN AS A CRITERION OF POLLUTION

There are some cases in which the dissolved oxygen figure does not afford a reliable index either of the existing pollution or the probability of future nuisance. For example, when the pollution is recent, a wrong inference may be drawn for there may be an abundant supply of oxygen present merely because sufficient time has not elapsed to permit the decomposable materials of the sewage to cause a serious drain upon the oxygen in the water. If such samples are kept for a time, a further depletion of oxygen will occur, and the extent of this change, if properly interpreted, will give information which is often of great value.

Dissolved oxygen should not be considered apart from temperature for temperature plays an important part in the rate at which digestion proceeds, heat favoring and cold retarding the process. It follows from this that, other things being equal, more sewage can be discharged into cold water than into warm water without danger that putrefactive changes will occur. The total amount of oxygen required to mineralize organic matters is doubtless the same in each case, but, where the water is cold, decomposition may be delayed until the sewage matters have been carried so far and been diluted so greatly as to preclude the possibility of nuisance from putrefaction.

Where the summer temperatures are high, the digestive process may conceivably be so greatly accelerated that practically all the decomposition which is possible may take place at the point at which the sewage is discharged. The oxygen is consumed more rapidly than it can be furnished from the supply originally contained in the water or by absorption from the atmosphere.

Temperature has as great an effect upon the digestion of sludge as upon the exhaustion of oxygen in water, although sludge is always devoid of oxygen. There seems to be no exception to the fact that the warmest temperatures of summer facilitate both the offensive and inoffensive forms of decomposition. It is worth knowing in this connection that the range in temperature which marks the changes of season in New York is not so great in the water as in the air, and is much less in the sludge at the harbor bottom than in the water which overlies it.

Evolutions of gas take place throughout the year, although they are particularly active in the summer and early autumn months.

Extent to Which the Digestive Capacity May Be Utilized

Proper limits to the extent to which the digestive capacity of the water can be utilized for the disposal of sewage should rest upon the digestive capacity of the water, aided perhaps, in some cases, by such procedures as dredging. There are many objections to dredging as a means of reinforcing the digestive capacity of water for sewage, and in a harbor like New York, where deposits of sludge are likely to form in inconvenient situations and where they produce nuisance from the beginning of their formation and through their removal by dredges, this kind of assistance may well be disregarded.

In the opinion of the Commission, the discharge of sewage into New York harbor should be so regulated and controlled as not unduly to exhaust the dissolved oxygen in the water, leading to the formation of sludge deposits which will cause offense or interfere with the interests of navigation or produce a considerable injury to the public health.

It will be proper to utilize the digestive capacity of the water within proper limits, and provided suitable restrictions are imposed, such as have just been mentioned and are more adequately dealt with in the Commission's standard of cleanness for the waters, no material harm will result.

The digestive capacity of the harbor is an asset of great value, permitting large savings to be made in the cost of the main drainage and disposal works which the City must build for the reasonable protection of its water highways.

It is impossible by means of oxygen analyses or otherwise to determine exactly the digestive capacity of New York harbor. Too many factors enter into the problem to permit of a solution so easily made. The area is great and the conditions various. In some respects the problem has to be studied as a whole and in others it must be resolved into its component parts for investigation. The volumes of sewage produced and the volumes of water available for its assimilation differ considerably in different localities. The necessity for any given degree of cleanness is not the same everywhere. The problem is complicated by the oscillating movement of the tide. The measure of the digestive capacity of inland rivers, known as the dilution method, customarily used by engineers, does not apply to New York harbor, where the movement of the tide makes it impossible to estimate with any reasonable degree of accuracy how much water is available for purposes of diluting the sewage.

The digestion of sewage by water, as relates to New York, has been carefully studied by the Metropolitan Sewerage Commission and discussed in a report issued in August, 1912. The report is accompanied by the reports of eight sanitary experts who were called upon to investigate the situation independently of one another and express an opinion as to the restrictions and safeguards which should control the discharge of sewage into New York harbor. A summary of the requirements follows:

1. Garbage, offal or solid matter recognizable as of sewage origin shall not be visible in any of the harbor waters.

2. Marked discoloration or turbidity, effervescence, oily sleek, odor or deposits, due to sewage or trade wastes, shall not occur except perhaps in the immediate vicinity of sewer outfalls, and then only to such an extent and in such places as may be permitted by the authority having jurisdiction over the sanitary condition of the harbor.

3. The discharge of sewage shall not materially contribute to the formation of deposits injurious to navigation.

4. Except in the immediate vicinity of docks and piers and sewer outfalls, the dissolved oxygen in the water shall not fall below 3.0 cubic centimeters per liter of water.* Near docks and piers there should always be sufficient oxygen in the water to prevent nuisance from odors.†

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*With 60 per cent. of sea water and 40 per cent. of land water and at the extreme summer temperature of 80 degrees F., 3.0 cubic centimeters of oxygen per liter corresponds to 58 per cent. of saturation.

†For modification of Standard of Cleanness as regards oxygen content, see Part III, Chap. I, pages 154 and 218.

5. The quality of the water at points suitable for bathing and oyster culture should conform substantially as to bacterial purity to a drinking water standard. It is not practicable to maintain so high a standard in any part of the harbor north of the Narrows, or in the Arthur Kill.

CALCULATION OF DILUTION REQUIRED

Dilution Required

As a result of observation and experiment in various parts of the world, engineers have formed opinions as to the amount of sewage which can safely be discharged into a natural body of water, such as an inland river or lake. The word safely here refers solely to the chance of producing a nuisance, chiefly odor. It has no relation to the effect which the sewage may have upon health.

According to the opinion of American engineers, the dilution must be in the proportion of at least 20 or 25 parts of water to one part of ordinary sewage and there may be conditions where a nuisance may result where the dilution amounts to nearly 50 parts of water to one part of sewage. When the proportion of sewage to water is greater than this, the capacity of the water is likely to be overtaxed. These supposedly safe ratios of dilution are based upon the assumption that the water with which the sewage is mixed is clean and possesses its normal amount of oxygen. Where the water is polluted to begin with the necessary dilution must be much greater.

In the Eighth Report of the Royal Commission on Sewage Disposal of Great Britain, issued at the end of 1912, it is recommended that where the dilution of sewage to water is between 150 and 200 times, the sewage should be purified so that the effluent will not contain more than 60 parts of suspended matter per million and that only when the dilution exceeds 500 times the volume of sewage should crude sewage be permitted to be discharged into a water course. These figures refer to English sewage, which is about 6 times as concentrated as American sewage, and to the water of inland rivers and lakes, but the Royal Commission holds the opinion that the proportions hold generally true for tidal waters also.

It is worthy of note that the observations upon which American and English experts base their opinions have been made where sewage has been discharged into inland bodies of water. There has been no study of the discharge of sewage into tidal estuaries which would permit of safe ratios to be stated with positiveness for salt water. Such investigations as have been made indicate that sewage solids settle more rapidly in salt water than in land water, and it is believed that gallon for gallon, land water will dispose, in a normal manner, of more sewage than sea water.

It is not always clear how the dilution of sewage can be calculated in sea water. The same, or nearly the same, water often flows backward and forward for days near a sewer outfall, while the discharge of sewage is continuous. Under these circumstances the sewage flow is irregular and its calculation is involved in uncertainty.

Errors which may be made in such calculations include the assumption that:

(*a*) The flow of sewage is uniform during the 24 hours. It may vary as much as 50 per cent. at different hours.

(*b*) The flow of tidal water is uniform. It is quite the reverse. Aside from the fact that the currents at each turn must gradually slow down to the stopping point and then gradually increase to the normal strength of flow, winds, heavy rain, snow and intense cold may each produce a decided effect upon the volume of water moving in a harbor.

(*c*) The sewage matters become immediately and thoroughly mixed with the waters. The opposite is the fact. Dispersion and diffusion are difficult to accomplish and consequently there are many kinds and degrees of stagnation.

(*d*) The sewage remains sewage after it is well mingled with the water. This is not true. Chemical changes at once set in.

(*e*) The waters into which the sewage is discharged are free from pollution to begin with. This assumption, however warranted in dealing with an inland river, is quite contrary to the fact as related to New York harbor.

The changes which sewage undergoes when it is discharged into a natural body of water should be carefully kept in mind, and the mistake, often made, of assuming that the sewage remains and can be reckoned with as sewage after admixture should be avoided. In no other way is it possible to obtain an accurate understanding of the subject. It is wrong to speak of sewage matters as sewage two or three hours after they have been discharged into a tidal estuary. Some of the original ingredients may still exist, but the chances are all against the continuance of any of them in an unaltered condition except the grosser solids and such others as may be able to persist in greatly diluted form.

Oxygen Required

It is impossible to say with any useful degree of accuracy how many pounds of oxygen one million gallons of sewage will require in order that the putrefiable ingredients may be rendered inert. The two ways of approaching this subject, that is, by analysis and incubation tests, are, unfortunately, too artificial to show what can reasonably be expected in nature. Predictions as to the amount of oxygen which would be present if a given quantity of sewage was to be discharged into a given quantity of water must, in the present state of knowledge, be considered unreliable.

But if it is impossible to calculate the oxygen requirements of sewage or express in percentages the proportions of sewage to water which may be present throughout a harbor, it is feasible to state, in at least approximate terms, the relation which exists between the volume of sewage and the volume of water present under various circumstances and such calculations may be of some value. They are likely to prove of greatest service when they are expressed in a simple way and are used with other data as a means of obtaining a general opinion of the case.

It was in this way, and with all the restrictions and qualifications which a knowledge of the situation imposed, that Professor Adeney, in a report to the Metropolitan Sewerage Commission, calculated the dilution of sewage in New York harbor. (See p. 95, Report Metropolitan Sewerage Commission, August, 1912.)

Calculations of Dilution

Taking his data from the published reports of the Commission, Professor Adeney calculated that about 59,400,000 cu. ft. of sewage flowed into the whole harbor during a tidal cycle of 12 lunar hours. Inasmuch as about 23 per cent. of the water of the harbor flowed out on the ebb tide, the same percentage of the contribution of sewage would flow to sea at the same time, leaving about 77 per cent. mixed with the harbor waters at mean low tide. The quantity of liquid sewage matters subsequently remaining within the harbor would increase with each succeeding tidal cycle until the quantity which passed out with the ebb tide became equal to that which drained into the harbor during the tidal cycle. This would occur when the total volume of liquid sewage, remaining intermixed with the harbor waters at mean low tide had become equal to about 195,500,000 cu. ft., which it would do after about 20 tidal cycles. The volume of liquid sewage matters passing out of the harbor through the Narrows would then continue to equal the volume of liquid sewage matters flowing into the harbor during a complete tidal cycle. That is, if 59,490,000 cu. ft. of sewage passed out of the harbor with each 12,310,000,000 cu. ft. of ebbing tide, the dilution of sewage to water would be in the proportion of 1 to 200 and the dilution to the liquid sewage matters remaining in the harbor at mean low tide would be in like proportion.

Both at the beginning and end of his calculation, Professor Adeney took pains to fully explain that this calculation did not, as no calculation could, truly represent the facts.

In a report by Messrs. Black and Phelps, made to the Board of Estimate and Apportionment of New York in 1909, the question of dilution is dealt with at length, for it was believed to have an important bearing on the question of dissolved oxygen and the authors considered that the oxygen should not fall below 70 per cent. of the amount which would be present if the water was saturated with it.

The sources of the water in each principal part of the harbor were assumed in accordance with volumes and velocities stated by the Coast and Geodetic Survey in 1886, and the proportion of water from each source was apportioned by the authors as, in their judgment, seemed correct. For convenience—these volumes were reduced to percentages of the whole and each was given a characteristic letter to facilitate computation. A series of equations was derived and the composition of the water of each part of the harbor was calculated for various tidal periods.

These studies were taken by the authors to indicate that the volume of pure sea water which entered the harbor between the Narrows and Throgs Neck every 12 hours was 29,135 million gallons and that this contained under summer conditions 1,946,218 pounds of dissolved oxygen. It was considered that if this oxygen were to be reduced by sewage to 70 per cent. of saturation, 583,865 pounds would be lost in 12 hours. The total volume of water in the harbor within the limits named was taken to be 251,418 million gallons, and it was stated that if this were reduced to 70 per cent. of saturation, it would absorb in 12 hours from the atmosphere 0.95 per cent. of its saturation value of 159,550 pounds.

The oxygen absorbed from the atmosphere plus the oxygen from the pure sea water would give a total of 743,415 pounds of oxygen. Finally, assuming that the sewage would be produced at the rate of 100 gallons per capita per day, the authors arrived at the opinion that the natural supply of oxygen would be sufficient to care for the sewage of a population of 7.4 millions, provided the sewage was discharged at the two ocean entrances.

A study of the dissolved oxygen reduced the difficulty considerably by showing how much oxygen has been used up and how much remains, thus giving a better knowledge of the water's capacity for sewage than would otherwise be obtainable.

STATE OF THE HARBOR WITH RESPECT TO DISSOLVED OXYGEN FROM 1911 TO 1913

Since 1909 the Metropolitan Sewerage Commission has given close attention to the amount of oxygen present in the water. Floating laboratories have been fitted out with every requisite for careful analytical work and these have been sent to all parts of the harbor to collect samples of the water and analyze them. The object of this field work has been twofold: First, to determine the extent to which the digestive capacity of the water was being exhausted and, second, to determine how that capacity could safely be utilized in the future.

The degree to which the oxygen is exhausted has been determined by comparing the amount of oxygen which is present with the known quantity which would be present if the water were unpolluted. The standard for comparison is the amount of oxygen which exists in unpolluted water and is called the saturation value. The calculation assumes that if it were not for the sewage and other wastes which enter the harbor, the saturation values would obtain. Tests of the oxygen in the polluted tributaries of New York harbor and in uncontaminated sea water and determinations of the ammonias, nitrites and nitrates in New York harbor and elsewhere have proved this assumption to be correct. The saturation value is taken from tables based on carefully made laboratory experiments. The amount of oxygen in the water is conveniently expressed as cubic centimeters per liter of water and as percentages of the saturation value.

The amount of oxygen present in unpolluted water varies according to the salinity and temperature of the water. The warmer and salter the water, the less oxygen it can contain. These differences are taken into account in calculating the results of the analyses. In very careful investigations, it is desirable to give attention to the amount of oxygen actually found, as well as to the percentage, because it is the actual amount of oxygen and not its relative amount, or percentage of saturation, which determines whether the water will, or will not, putrefy. In all the Commission's tables of dissolved oxygen, these two methods of stating the results have been employed.

The samples of water which were tested were obtained in bottles protected by special apparatus from contamination by air and represented the exact condition of the water at the time and place of collection. The samples were always the best that could be obtained at the time and place. In no case have samples been taken at the mouths of sewers or within the known reach of currents of exceptionally polluted water. Where samples have been collected close to shore, or in particularly polluted localities, the results have been excluded from the averages.

A prompt analysis of the water showed the amount of oxygen which was consumed by the sewage materials up to the time when the sample was collected. A knowledge of the extent to which the sewage materials would exhaust the oxygen, when more time was allowed for decomposition, was obtained by keeping the sample on hand for some time before examining it. Such storage is termed incubation. In practice the incubated samples were collected at the same time as samples that were analyzed at the time of collection, and then kept for a definite period at a uniform temperature without access of air. Several hundred samples of the harbor water were incubated by the Commission. In practically all cases the oxygen was greatly depleted.

Changes produced in the oxygen and in other chemical constituents on incubation are shown in the tables accompanying this report.

Summary of Facts Established to November, 1911

The results of the analyses made up to November, 1911, have been published by the Commission in its large report of 1912, together with various maps and diagrams intended to facilitate an understanding of the facts. The total number of analyses reported was 2,342.

The work done since 1911 makes available the results of 1,368 more analyses and it seems desirable that the most important facts contained in this mass of information should be published.

In the report of 1912, the inner harbor, by which is meant those portions which lie north of the Narrows and south of Hell Gate in the East river and Mount St. Vincent on the Hudson river, was shown to be seriously polluted with sewage. During the warm summer months the water at the Narrows averaged 76 per cent., in upper New York Bay 70 per cent., in the lower East river about 57 per cent., and that in the southern part of the Harlem river about 30 per cent. of the amount which they would have held had there been no pollution.

The water of the incoming tide was better than the water of the outgoing tide, but the difference was not great. The tides produced less improvement in the lower East river than anywhere else. The upper bay was a great equalizer, so far as oxygen was concerned, in this capacity standing between the relatively clean water of the lower bay and the heavily polluted East and Hudson rivers and the Kill van Kull in this respect.

Outward flowing currents carry the polluted waters of the Hudson, East river and Kill van Kull into the upper bay, where they mix with the cleaner waters left there at the end of the last flood tide. On the inward flowing currents, the bay is to some extent refreshed by the waters of the ocean which flow in through the Narrows.

The analyses reported upon up to August, 1912, show that there was little difference in the amount of oxygen at different depths. A little more oxygen generally existed at the bottom than at the top. Less oxygen existed near the shores than farther out in midstream.

Owing to the rapidity of the main tidal currents which flow in places at a velocity of from 6 to 8 knots per hour, the waters in all the main parts of the harbor are well mixed from top to bottom and from side to side except in certain bays and between the pierhead lines and the shores. This statement does not refer to the actual top, bottom or sides; these are always far more polluted than the water in the main body of the stream. It refers to the water which lies from two to three hundred feet beyond the pierhead line on one shore to an equal distance from the opposite shore and between a point within 5 feet of the top to a depth about 10 feet above the bottom. At the very top, sides and bottom, the water is far more polluted than any of the Commission's analytical data indicate. In some localities, it is impossible to tell such water from sewage itself. Over all the water in the Harlem and Lower East rivers flow considerable quantities of grease and fecal matters at times.

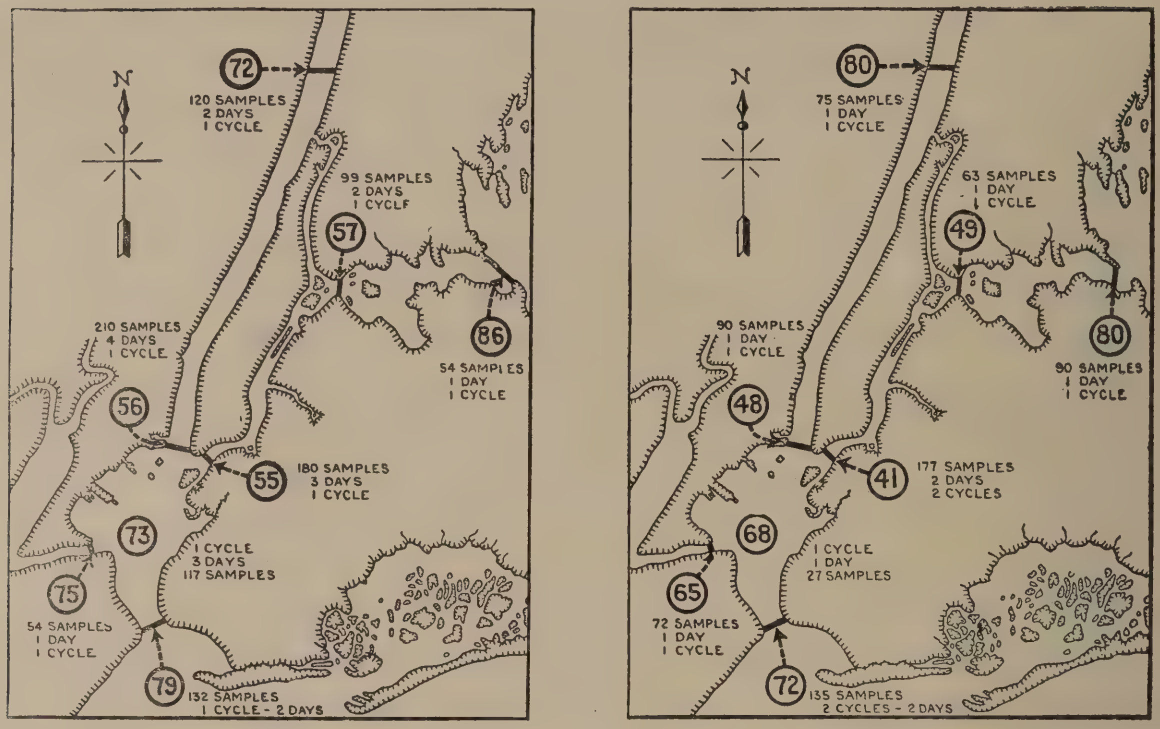
There is considerable difference in the freedom with which the tidal currents flow, deep bays and comparatively shallow indentations in the shore lines affording opportunities for slack water in which the sewage materials gather and remain. Irregularities in the bottom sometimes cause extensive upwellings of water in the center of the main currents and occasionally a sharp bend in the channel will cause a remarkable overturning of the water.

Overturnings are also caused by strong winds which, blowing along the surface force the water at and near the top to the lee shores and pile it up there, the underlying waters flowing outward from beneath to maintain an equilibrium. The continual movement of vessels, some of which draw over 30 feet, doubtless has its effect in promoting the circulation which has been observed.

The changing temperature of the surface water under the influence of the sun and air probably has an effect in producing a vertical circulation which cannot wholly be neglected. For six months in the year the surface may be made warmer or cooler than the water below and these differences undoubtedly produce an effect upon the circulation.

Tending to prevent a thorough mixture of the sewage with the harbor waters is the great weight of the incoming sea water due to its low temperature and its high salinity. This weight is relatively greater than the weight of an equal volume of sewage and the sea water accordingly tends to sink and remain at the bottom. On account of its grease, entrained air, low salinity and higher temperature, the sewage has a tendency to stay at the surface of the water where it is discharged. That it does not do so any more than is apparent is largely due to the strong mixing action produced by the interacting currents in the main tidal channels.

Although the waters are well mixed in the main tidal channels, sewage which is



1911

1913

FIG. 37

Dissolved Oxygen in the Water Collected in the Cross-Sections

discharged near the shores tends to cling there and be carried along by the tide without promptly mixing with the main body of water in the open channels. The water between the slips and piers is often very foul as can be seen not only from analyses, but by the unaided senses. The refreshing effect of the tide is less than might be expected; it is least effective where it is most needed; there is scarcely any perceptible effect in the innermost parts of the harbor.

The Increasing Exhaustion of Oxygen

The samples collected since November, 1911, represent the condition of the water in the principal parts of the harbor within the State of New York. In some cases samples were taken within the New Jersey State line. For the most part, the sampling was done at cross-sections which experience had shown were capable of giving, with the least expenditure of time and money, the most comprehensive knowledge of the condition of the water. Some of the sections were in the most important parts of the harbor as regarded from the standpoint of congestion of population and traffic. Others were so located as to command the main tidal currents flowing in and out of the harbor. Special interest attaches to the Harlem, Lower East river, Narrows and

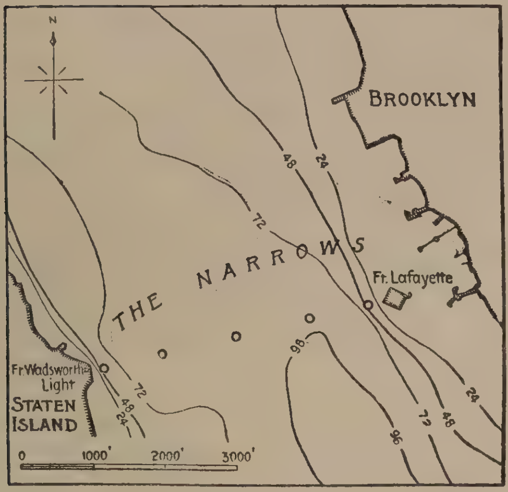


FIG. 38

The Narrows

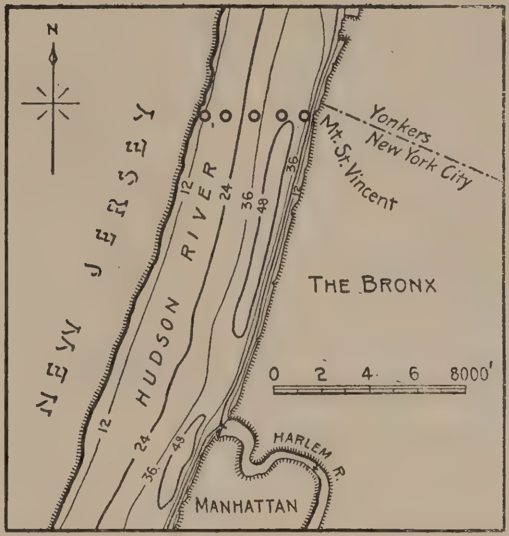


FIG. 39

Hudson River at Mount St. Vincent

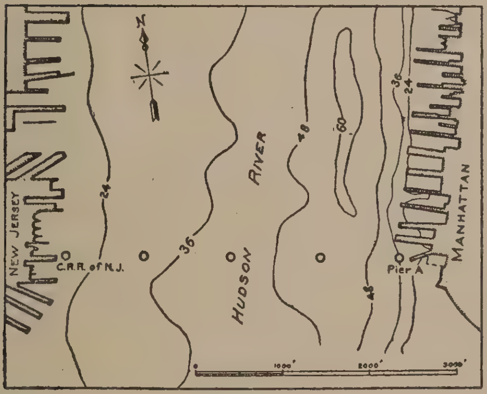


FIG. 40

Hudson River at Mouth

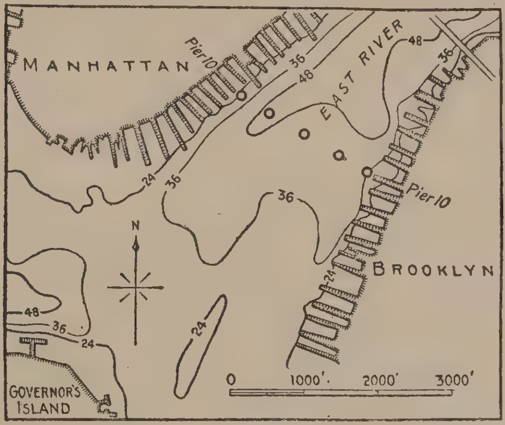


FIG. 41

East River at Pier 10

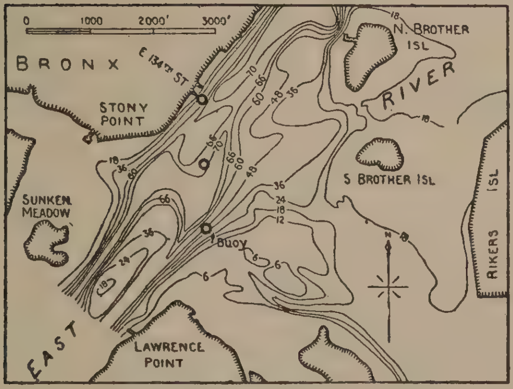


FIG. 42

East River at Lawrence Point

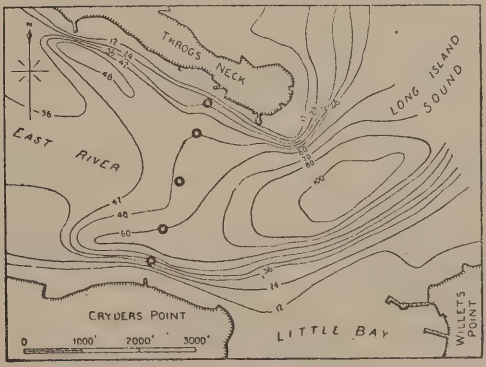


FIG. 43

East River at Throgs Neck

Location of Cross-Sections where Samples of Water for Dissolved Oxygen Tests were Taken in 1913 the mouth of the Hudson river. The location of sections in 1911 and 1913 is shown in Fig. 37 and details as to depth of water, etc., are shown in Figs. 38 to 44, inclusive.

The analyses show that the water is becoming decidedly more contaminated each year. This is particularly noticeable in three large groups of analyses made during the two months of June and July in 1909, 1911 and 1913, respectively. Sketch maps of the harbor divisions, showing the oxygen in each, are given as Fig. 45.

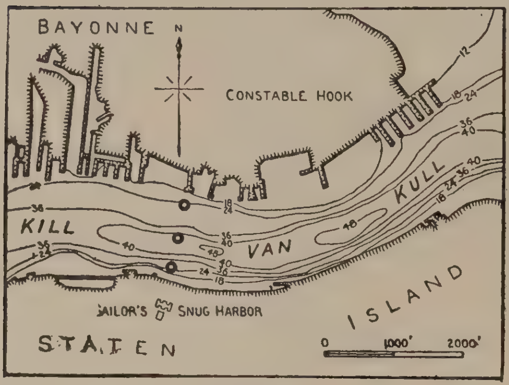


FIG. 44

Kill van Kull at Sailor's Snug Harbor

In order to compare the summer conditions during June and July of the three years mentioned, the oxygen results obtained have been plotted on maps. If more than one analysis has been made at one point, the average result has been taken without respect to depth. This was permissible in view of the fact that the oxygen did not vary materially with the depth at the points selected. The result of the average has been plotted alongside of the point where the sample was located on the map. Arrows and small numerals show how many samples were taken and whether on ebb or flood currents at each spot. See Maps A, B, C and D, following pages 654, 670 and 706. In Figs. 46 to 55, appended to this report, are plottings of the data which show the distribution of oxygen throughout a tidal cycle of 12 lunar hours, and through the cross-sections where analyses were made.

At the mouths of the Hudson and East rivers, the per cent. of oxygen was in the

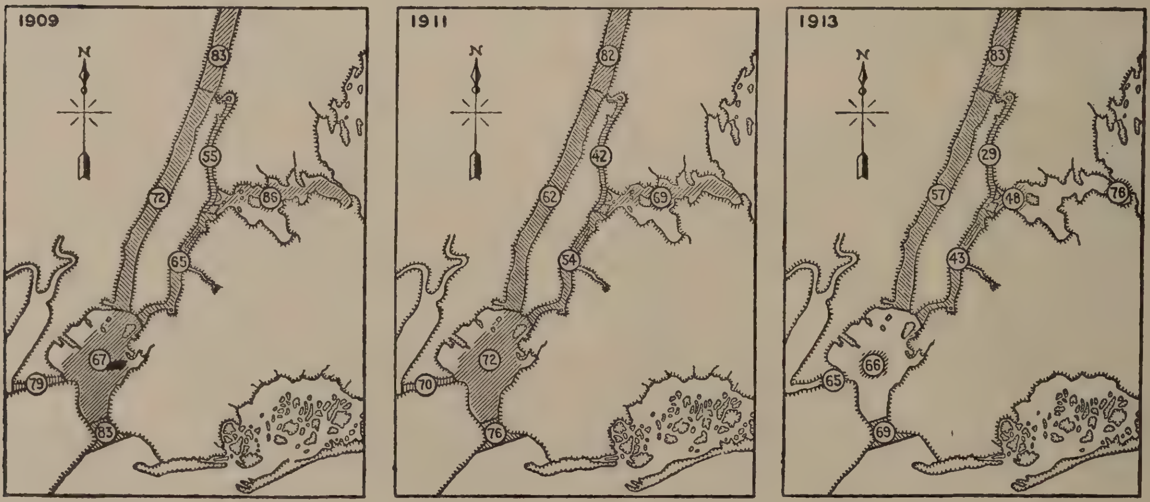


FIG. 45

Comparison Between the Dissolved Oxygen in New York Harbor Water in the Years 1909, 1911 and 1913 neighborhood of 58 on ebb currents and from 60 to 70 on flood currents during the summer of 1909. At the Narrows the per cent. on outgoing currents was from 72 to 81, and on incoming currents in the neighborhood of 96 per cent. At Throgs Neck the oxygen on outgoing currents varied between 87 and 97 per cent. and on incoming currents it was often 100 per cent. In Upper New York bay outgoing currents contained between 58 and 73 per cent., while incoming currents contained between 63 and 75 per cent.

In the summer of 1911 the oxygen was less on both outgoing and incoming currents than had previously been observed. At the mouths of the Hudson and East rivers the outgoing currents contained from 50 to 59 per cent. and incoming currents from 54 to 60 per cent. At the Narrows the outgoing currents contained 65 per cent. and the incoming currents 83 per cent. Incoming currents in the Kill van Kull contained from 62 to 66 per cent. In Upper New York bay outgoing currents contained from 59 to 65 per cent. and incoming currents from 62 to 70 per cent. At Throgs Neck, outgoing currents contained 71 per cent. and incoming currents 84 per cent. In the Hudson opposite Mount St. Vincent, about 2½ miles north of Manhattan Island, the incoming currents ranged from 64 to 72 per cent. and the outgoing currents from 66 to 83 per cent. of oxygen.

In the summer of 1913, the range of dissolved oxygen at the mouth of the Hudson was from 43 to 53 per cent. on incoming currents and from 47 to 60 per cent. on outgoing currents. At the mouth of the Lower East river the range was from 39 to 48 per cent. on incoming and from 31 to 40 on outgoing currents. These figures show that the oxygen was becoming markedly depleted in the Lower East river. At the Narrows the range was from 67 to 74 per cent. on incoming and from 67 to 78 per cent. on outgoing currents. At the Kill van Kull the range was from 64 to 66 per cent. on incoming and from 65 to 67 on outgoing currents. At Throgs Neck from 76 to 85 per cent. of oxygen was found on incoming currents and 73 to 83 per cent. on outgoing currents. In the Hudson at Mount St. Vincent, incoming currents held from 72 to 95 per cent. and outgoing currents from 76 to 85 per cent. of the normal amount of oxygen. Upper New York bay in 1913 contained about 70 per cent. on incoming and outgoing currents.

Averaging all the analyses made in the Lower East river except a few in 1909 in the excessively polluted region of Wallabout bay, it appears that the oxygen in this important part of the harbor averaged, during the months of June and July, 62.0 per cent. in 1909, 54.6 per cent. in 1911 and 36.6 per cent. in 1913.

The oxygen in the Hudson opposite Manhattan Island, considering all the analyses made between the confluence of the Harlem and the Hudson's mouth, has been 62.8 per cent. in 1909, 64.5 per cent. in 1911 and 52.2 per cent. in 1913.

The oxygen figures for the Harlem make no attempt to cover the condition of that grossly polluted body of water. The 92 analyses made of this water show that the oxygen averaged 47.7 per cent. in 1909, 46.1 per cent. in 1911 and 27.5 per cent. in 1913. The data for 1911 represent 18 samples collected on ebb tide in July.

It will be seen from these figures that all the waters surrounding Manhattan are becoming more contaminated as time proceeds and that the change as measured by the dissolved oxygen figures is rapid.

Particular interest attaches to the Lower East river on account of the great importance of this congested part of the harbor and because of the great difficulty with which the conditions can be improved. In 1913 the average of 15 analyses made in the middle of the East river on outgoing currents was 31 per cent. and still lower figures than these were found in this locality. At the same point and under the same circumstances there was 57 per cent. in the year 1911 and, in 1909, 61 per cent. The oxygen had become reduced from about two-thirds to about one-third of the saturation value in two years.

Essential Facts Relating to the Cross-Sections.

During 1911 and 1913 detailed examinations of cross-sections of the main tidal channels of the harbor were made a special feature of the work. From three to five points spaced at equal distances apart were taken across the channels, and at each point samples were collected from three depths. Sampling usually began near the beginning or end of a tide and was continued throughout the succeeding tidal cycle, Seven of these cross-sections were studied in 1913, the number of samples collected from the most important of them being 167.

Comparing the work of 1913 with that done in 1911 and stating the case in general terms, the diffusion of the sewage in the water was not as complete in 1913 as it was in 1911; the curves plotted from the data show the variations plainly.

In 1911 there was often a gradual decrease in the effects of pollution at the beginning of flood currents; in 1913 a rapid rise occurred. The rise in oxygen was not only more abrupt, but was not uniform at all points in the cross-section examined.

Variations in the quality of the water at different depths were often pronounced in 1913, whereas such differences were inconspicuous in 1911.

With the exception of the Hudson river at Mount St. Vincent there was evidence of greater pollution in all the cross-sections in 1913 than in 1911. At Mount St. Vincent there was somewhat more oxygen in 1913 than formerly. At this point the water was better during the ebb current than when the current flowed from the direction of the sea. It is accounted for by the fact that the sea water brought sewage materials from New York City, whereas the ebb currents were from the relatively little polluted Upper Hudson. This difference was marked in 1913. In 1911 there was more oxygen at the top than at the bottom during flood currents in most parts of the harbor, but in 1913 there was slightly more at the bottom and in midstream than at the top.

There was less oxygen at the mouth of the Hudson river in 1913 than in 1911 and the variation was greater in the latter year, both as to the amount of oxygen found at different depths and at different points between the shores. In 1911 there was a gradual rise in the oxygen following the beginning of flood currents; in 1913 this rise was abrupt and marked.

At the mouth of the East river, the water was much more polluted in 1913 than in 1911, as measured by the oxygen. At the beginning of flood currents there was a sharp rise in the oxygen; a very gradual rise occurred at this place under the same tidal conditions in 1911. Whereas in 1911 there had occurred a slight fall in the amount of oxygen throughout the ebb current, in 1913 this fall was decided. Of all these differences, chief significance attaches to the fact that the Lower East river has been growing more and more polluted.

Summary of Details Relating to Special Localities

The Lower East River.—It is not apparent why the Lower East river should increase so rapidly in pollution as it has in the last four years. Some increase might be expected from the increase in the population whose sewage is directly tributary to this part of the harbor, but the increase would not, apparently, suffice to produce such a change in the oxygen figure as has been observed. It is possible that the increasing pollution of the Harlem and Upper East rivers, which are immediately tributary to the Lower East river, and the polluting effect of the Gowanus Flushing Tunnel, which discharges at the mouth of the Lower East river, may account in large part for the reduction.

The condition of the Lower East river calls imperatively for improvement. As shown in Preliminary Report No. VI* of this Commission, issued February, 1913, the quantity of sewage now discharging into this part of the harbor is very large and will greatly increase in future. The ratio of sewage to the excess of water flowing seaward was as 1 to 5.9 in the year 1910 and by the year 1940 will be as 1 to 3.2.

It is probable that there is no other city in the world within whose crowded districts so much sewage is discharged. In 1910 the daily addition of sewage was 264 million gallons from a population of about 2,000,000. This quantity will increase until by the year 1940 it is estimated that there will be discharged into the East river between Hell Gate and the Battery 454 million gallons from a population of about

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*Part II, Chap. II, page 46, this report.

3,223,000. In addition to this there will be the densely polluted water of the Harlem flowing in at each tide.

The large demand which the sewage makes upon the oxygen in the rest of the harbor is doubtless due in part to the polluted water of the East river, in part to the sewage which directly enters it and in part to deposits of sewage sludge which lie on the bottom. These deposits are stirred up by the movement of vessels and by tidal actions and, putrefying, give off products which consume a good deal of the oxygen.

The report of this commission issued August, 1912, shows the location of the most extensive sludge deposits. They are mostly in the more open parts of the harbor. Other, if less extensive, deposits exist, notably in the slips and in innumerable quiet places around the water front.

Excepting for the deposits of sludge along the shores, there is practically no sludge upon the bottom of the Lower East river. The water of that part of the harbor is deficient in oxygen because of the demand which is made by the sewage which directly enters it and because the water which enters it from parts of the harbor which are themselves polluted is deficient in oxygen.

The Harlem River.—Analyses are scarcely capable of showing the condition of the Harlem river. An inspection of the water affords far more striking evidence of the intensity of pollution. In the neighborhood of 110th Street the water is often so contaminated as to resemble undiluted sewage. The water is turbid and greasy and fecal matters are conspicuously present. This appearance sometimes extends from shore to shore. The musty, sweetish odors are characteristic of fresh sewage. Deposits of sewage materials occur here and putrefy, giving off, in summer, bubbles of gas which burst at the surface of the water causing it to resemble the appearance of falling rain.

The dilution of sewage with water in the Harlem river was, in the year 1910, very small, no matter how reckoned. The ratio of the sewage to the net ebb flow of the tide, which is the quantity of water which flows in one direction in excess of the water which flows in the opposite way was as 1 to 2.2. By the year 1940, the increasing amount of sewage will reduce this dilution so that it will be as 1 is to 0.85. In other words, by 1940 there will be more sewage entering the Harlem river than water passing through that stream.

The condition of the Harlem is the most serious which confronts the City of New York at the present time. Not only is the water objectionable from the standpoint of the Harlem itself, but, pouring out alternatively into the Hudson and East river, the polluted Harlem adds materially to the pollution of each. Six samples, collected at its junction with the Hudson in 1911, when the current was carrying the water of the Harlem into the Hudson, contained but 17 per cent. of oxygen, and on another occasion when the water was flowing into the East river at Hell Gate the oxygen was about as far gone.

The Upper East River.—The waters of the Upper East river are, as yet, not so heavily polluted as to require the immediate construction of extensive sewage disposal works. Yet the increasing pollution to which this part of the harbor will be subject in the next thirty years leaves little doubt but that the conditions which now exist in the Lower East river and Harlem will be repeated unless steps are taken to protect the waters. Plans should be adopted for the future without delay.

Already the water at the west end of the Upper East river has been found to contain only about 45 per cent. of oxygen when the currents are flowing northward, and a long series of analyses at this point made in the summer of 1913 showed that the water was never in satisfactory condition.

Some large sewers discharge into the Upper East river and in the vicinity of their outlets the conditions of pollution are very bad. The discharge of the Hunt's Point sewer can often be seen a mile or more away. The existence of popular places of recreation in the Upper East river makes it especially desirable to keep this water reasonably clean.

The Hudson River.—Notwithstanding the relatively large amount of water in the Hudson available for diluting sewage and in spite of the considerable net discharge of this body of water seaward, the condition of the Hudson is fast becoming unsatisfactory. The best water obtainable from this part of the harbor in the summer of 1911 ranged from 56 to 63 per cent., and results in the vicinity of the lower figure have been common.

The Kill van Kull.—The dissolved oxygen in the Kill van Kull shows plainly the pollution to which that part of the harbor is subject. In 1913 the percentage was below 70. There was little difference between the quality of the incoming and outgoing tidal currents; the water which entered this part of the harbor was polluted in each case.

SECTION III

TABLES OF DISSOLVED OXYGEN IN THE WATER

INTRODUCTION TO TABLES CXVI, CXVII, CXVIII, CXIX

The dissolved oxygen found in the year 1911 at various localities, depths and tides, have been computed from the data contained in Table XXVII, Report of Metropolitan Sewerage Commission, 1912, pages 344-414. In Table CXIX of the present report is given a summary of the results of these calculations. Tables CXVI, CXVII and CXVIII give the results used in making these averages.

TABLE CXVI

Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1911

Averages for various parts of the harbor

Data for this table are contained in Table XXVII, Report of Metropolitan Sewerage Commission, 1912.

Location	Number of analyses	Averages: C. C. per litre	Averages: per cent. saturation	Samples included in the averages
Upper bay	195	4.35	73	92–94, 110–112, 260–274, 349–357, 373–381, 400–402, 841–843, 2038–2094, 2098–2109, 2113–2124, 2128–2139, 2143–2154, 2158–2169, 2230–2244, 2251–2265, 2275–2276, 2339.
Hudson river, below Spuyten Duyvil	345	3.47	61	20–22, 137–169, 275–310, 463–522, 538–551, 556–588, 903–947, 1579–1683, 2227–2229, 2266–2274, 2316–2318, 2336.
Hudson river, above Spuyten Duyvil	158	4.91	78	23–52, 170–181, 311–322, 352–355, 589–597, 1948–2037, 2337.
East river, below Hell Gate	217	3.06	55	95–106, 113–124, 598–642, 768–812, 815–816, 821–822, 825–828, 952–954, 1684–1773, 2338, 2342.
East river, above Hell Gate	253	3.99	69	53–91, 107–109, 125–127, 418–462, 523–537, 643–657, 694–699, 728–733, 955–960, 1894–1947, 2173–2226, 2301–2303, 2306–2308, 2334.
Harlem river	52	2.28	43	182–225, 833–840.
Kill van Kull	78	4.19	72	403–414, 844–855, 1774–1827.
The Narrows	168	4.43	78	358–360, 382–384, 876–902, 1474–1578, 2095–2097, 2110–2112, 2125–2127, 2140–2142, 2155–2157, 2170–2172, 2245–2250, 2287–2292.
Gowanus canal	25	1.90	20	12–19, 128–136, 690–693, 948–951.
Newtown creek	8	1.14	17	2319–2326.
Wallabout canal	2	1.67	30	2279–2280.
Long Island Sound	22	4.74	93	700–705, 722–727, 961–966, 2309–2311, 2333.
Newark bay	82	3.92	63	415–417, 856–867, 1828–1893, 2335.
Passaic river, near Newark	8	0.00	0	868–875.
Lower bay	44	5.39	97	361–366, 385–396, 734–753, 764–767, 2340–2341.
Buttermilk channel	68	2.91	54	3–11, 230–235, 240–242, 247–255, 323–328, 333–337, 340–345, 658–663, 668–679, 684–689.
Manhasset bay	16	5.24	97	706–721.
Cheesequake creek	10	5.44	100	754–763.
Atlantic ocean	9	5.66	100	367–372, 397–399.

1760 Total number of samples included in the averages.

NOTE.—The following samples are omitted, having been taken in slips and too near shore:

East river below Hell Gate, 813–814, 817–820, 823–824, 2281–2282, 2304–2305	12
East river above Hell Gate, 2283–2284, 2331–2332	4
Harlem river, 829–832, 2285–2286, 2293–2300, 2327–2330	18
Buttermilk channel, 1–2, 226–229, 236–239, 243–246, 256–259, 329–332, 338–339, 346–348, 664–667, 680–883, 2277–2278, 2312–2315	41
	75
Trip through Long Island Sound and Boston Harbor, 967–1473	507
Total omitted	582
Total included in averages	1760
Total analyses, Nos. 1–2342	2342

TABLE CXVII

Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1911
Averages of samples taken at Surface, Mid-depth and Bottom for various parts of the harbor

Data for this table are contained in Table XXVII, Report of Metropolitan Sewerage Commission, 1912.

Location	Depths											
	Surface				Mid-depth				Bottom			
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Upper bay.........	68	3.93	71	92, 110, 260, 262, 264, 266, 268, 270, 272, 349, 352, 355, 373, 376, 379, 400, 841, 2038, 2041, 2044, 2047, 2050, 2053, 2056, 2059, 2062, 2065, 2068, 2071, 2074, 2077, 2080, 2083, 2086, 2089, 2092, 2098, 2101, 2104, 2107, 2113, 2116, 2119, 2122, 2128, 2131, 2134, 2137, 2143, 2146, 2149, 2152, 2158, 2161, 2164, 2167, 2230, 2233, 2236, 2239, 2242, 2251, 2254, 2257, 2260, 2263, 2275, 2339.	60	4.48	75	93, 111, 273, 350, 353, 356, 374, 377, 380, 401, 842, 2039, 2042, 2045, 2048, 2051, 2054, 2057, 2060, 2063, 2066, 2069, 2072, 2075, 2078, 2081, 2084, 2087, 2090, 2093, 2099, 2102, 2105, 2108, 2114, 2117, 2120, 2123, 2129, 2132, 2135, 2138, 2144, 2147, 2150, 2153, 2159, 2162, 2165, 2168, 2231, 2234, 2237, 2240, 2243, 2252, 2255, 2258, 2261, 2264.	67	4.68	73	94, 112, 261, 263, 265, 267, 269, 271, 274, 351, 354, 357, 375, 378, 381, 402, 843, 2040, 2043, 2046, 2049, 2052, 2055, 2058, 2061, 2064, 2067, 2070, 2073, 2076, 2079, 2082, 2085, 2088, 2091, 2094, 2100, 2103, 2106, 2109, 2115, 2118, 2121, 2124, 2130, 2133, 2136, 2139, 2145, 2148, 2151, 2154, 2160, 2163, 2166, 2169, 2232, 2235, 2238, 2241, 2244, 2253, 2256, 2259, 2262, 2265, 2275.
Hudson river, below Spuyten Duyvil..	119	3.53	62	20, 21, 137, 140, 143, 146, 149, 152, 155, 158, 161, 164, 167, 275, 278, 281, 284, 287, 290, 293, 296, 299, 302, 305, 308, 463, 466, 469, 472, 475, 478, 481, 484, 487, 490, 493, 496, 499, 502, 505, 508, 511, 514, 517, 520, 538, 540, 542, 544, 546, 548, 550, 556, 559, 562, 565, 568, 571, 574, 577, 580, 583, 586, 903, 906, 909, 912, 915, 918, 921, 924, 927, 930, 933, 936, 939, 942, 945, 1579, 1582, 1585, 1588, 1591, 1594, 1597, 1600, 1603, 1606, 1609, 1612, 1615, 1618, 1621, 1624, 1627, 1630, 1633, 1636, 1639, 1642, 1645, 1648, 1651, 1654, 1657, 1660, 1663, 1666, 1669, 1672, 1675, 1778, 1781, 2227, 2266, 2269, 2272, 2316, 2336.	109	3.38	60	138, 141, 144, 147, 150, 153, 156, 159, 162, 165, 168, 276, 279, 282, 285,-288, 291, 294, 297, 300, 303, 306, 309, 464, 467, 470, 473, 476, 479, 482, 485, 488, 491, 494, 497, 500, 503, 506, 509, 512, 515, 518, 521, 557, 560, 563, 566, 569, 572, 575, 578, 581, 584, 587, 904, 907, 910, 913, 916, 919, 922, 925, 928, 931, 934, 937, 940, 943, 946, 1580, 1583, 1586, 1589, 1592, 1595, 1598, 1601, 1604, 1607, 1610, 1613, 1616, 1619, 1622, 1625, 1628, 1631, 1634, 1637, 1640, 1643, 1646, 1649, 1652, 1655, 1658, 1661, 1664, 1667, 1670, 1673, 1676, 1679, 1682, 2229, 2267, 2270, 2273, 2317.	117	3.47	62	22, 139, 142, 145, 148, 151, 154, 157, 160, 163, 166, 169, 277, 280, 283, 286, 289, 292, 295, 298, 301, 304, 307, 310, 465, 468, 471, 474, 477, 480, 483, 486, 489, 492, 495, 498, 501, 504, 507, 510, 513, 516, 519, 522, 539, 541, 543, 545, 547, 549, 551, 558, 561, 564, 567, 570, 573, 576, 579, 582, 585, 588, 905, 908, 911, 914, 917, 920, 923, 926, 929, 932, 935, 938, 941, 944, 947, 1581, 1584, 1587, 1590, 1593, 1596, 1599, 1602, 1605, 1608, 1611, 1614, 1617, 1620, 1623, 1626, 1629, 1632, 1635, 1638, 1641, 1644, 1647, 1650, 1653, 1656, 1659, 1662, 1665, 1668, 1671, 1674, 1677, 1680, 1683, 2230, 2268, 2271, 2316, 2318.

TABLE CXVII—Continued

Location	Depths											
	Surface				Mid-depth				Bottom			
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Hudson river, above Spuyten Duyvil..	54	5.18	82	23, 26, 29, 32, 35, 38, 41, 44, 47, 50, 170, 173, 176, 179, 311, 314, 317, 320, 552, 554, 589, 592, 595, 1948, 1951, 1954, 1957, 1960, 1963, 1966, 1969, 1972, 1975, 1978, 1981, 1984, 1987, 1990, 1993, 1996, 1999, 2002, 2005, 2008, 2011, 2014, 2017, 2020, 2023, 2026, 2029, 2032, 2035, 2337.	51	4.78	76	24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 171, 174, 177, 180, 312, 315, 318, 321, 590, 593, 596, 1949, 1952, 1955, 1958, 1961, 1964, 1967, 1970, 1973, 1976, 1979, 1982, 1985, 1988, 1991, 1994, 1997, 2000, 2003, 2006, 2009, 2012, 2015, 2018, 2021, 2024, 2027, 2030, 2033, 2036.	53	4.76	77	25, 28, 31, 34, 37, 40, 43, 46, 49, 52, 172, 175, 178, 181, 313, 316, 319, 322, 553, 555, 591, 594, 597, 1950, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016, 2019, 2022, 2025, 2028, 2031, 2034, 2037.
East river, below Hell Gate........	75	3.04	54	95, 98, 101, 104, 113, 116, 119, 122, 598, 601, 604, 607, 610, 613, 616, 619, 622, 625, 628, 631, 634, 637, 640, 768, 771, 774, 777, 780, 783, 786, 789, 792, 795, 798, 801, 804, 807, 810, 815, 821, 825, 827, 952, 1684, 1687, 1690, 1693, 1696, 1699, 1702, 1705, 1708, 1711, 1714, 1717, 1720, 1723, 1726, 1729, 1732, 1735, 1738, 1741, 1744, 1747, 1750, 1753, 1756, 1759, 1762, 1765, 1768, 1771, 2338, 2342.	73	3.06	55	96, 99, 102, 105, 114, 117, 120, 123, 599, 602, 605, 608, 611, 614, 617, 620, 623, 626, 629, 632, 635, 638, 641, 769, 772, 775, 778, 781, 784, 787, 790, 793, 796, 799, 802, 805, 808, 811, 816, 822, 826, 828, 953, 1685, 1688, 1691, 1694, 1697, 1700, 1703, 1706, 1709, 1712, 1715, 1718, 1721, 1724, 1727, 1730, 1733, 1736, 1739, 1742, 1745, 1748, 1751, 1754, 1757, 1760, 1763, 1766, 1769, 1772.	69	3.08	55	97, 100, 103, 106, 115, 118, 121, 124, 600, 603, 606, 609, 612, 615, 618, 621, 624, 627, 630, 633, 636, 639, 642, 770, 773, 776, 779, 782, 785, 788, 791, 794, 797, 800, 803, 806, 809, 812, 954, 1686, 1689, 1692, 1695, 1698, 1701, 1704, 1707, 1710, 1713, 1716, 1719, 1722, 1725, 1728, 1731, 1734, 1737, 1740, 1743, 1746, 1749, 1752, 1755, 1758, 1761, 1764, 1767, 1770, 1773.
East river, above Hell Gate........	85	4.00	69	53, 56, 59, 62, 65, 68, 71, 74, 77, 80, 83, 86, 89, 107, 125, 418, 421, 424, 427, 430, 433, 436, 439, 442, 445, 448, 451, 454, 457, 460, 523, 526, 529, 532, 535, 643, 646, 649, 652, 655, 694, 697, 728, 731, 955, 958, 1894, 1897, 1900, 1903, 1906, 1909, 1912, 1915, 1918, 1921, 1924, 1927, 1930, 1933, 1936, 1939, 1942, 1945, 2173, 2176, 2179, 2182, 2185, 2188, 2191, 2194, 2197, 2200, 2203, 2206, 2209, 2212, 2215, 2218, 2221, 2224, 2301, 2306, 2334.	84	3.99	69	54, 57, 60, 63, 66, 69, 72, 75, 78, 81, 84, 87, 90, 108, 126, 419, 422, 425, 428, 431, 434, 437, 440, 443, 446, 449, 452, 455, 458, 461, 524, 527, 530, 533, 536, 644, 647, 650, 653, 656, 695, 698, 729, 732, 956, 959, 1895, 1898, 1901, 1904, 1907, 1910, 1913, 1916, 1919, 1922, 1925, 1928, 1931, 1934, 1937, 1940, 1943, 1946, 2174, 2177, 2180, 2183, 2186, 2189, 2192, 2195, 2198, 2201, 2204, 2207, 2210, 2213, 2216, 2219, 2222, 2225, 2302, 2307.	84	3.98	69	55, 58, 61, 64, 67, 70, 73, 76, 79, 82, 85, 88, 91, 109, 127, 420, 423, 426, 429, 432, 435, 438, 441, 444, 447, 450, 453, 456, 459, 462, 525, 528, 531, 534, 537, 645, 648, 651, 654, 657, 696, 699, 730, 733, 957, 960, 1896, 1899, 1902, 1905, 1908, 1911, 1914, 1917, 1920, 1923, 1926, 1929, 1932, 1935, 1938, 1941, 1944, 1947, 2175, 2178, 2181, 2184, 2187, 2190, 2193, 2196, 2199, 2202, 2205, 2208, 2211, 2214, 2217, 2220, 2223, 2226, 2303, 2308.

TABLE CXVII—Continued

Location	Depths											
	Surface				Mid-depth				Bottom			
	No. of analyses	Averages: C. C. per litre	Averages: per cent. saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Harlem river.......	26	2.27	42	182, 184, 186, 188, 190, 192, 194, 196, 198, 200, 202, 204, 206, 208, 210, 212, 214, 216, 218, 220, 222, 224, 833, 835, 837, 839.	—	—	—	No mid-depth samples.	26	2.28	43	183, 185, 187, 189, 191, 193, 195, 197, 199, 201, 203, 205, 207, 209, 211, 213, 215, 217, 219, 221, 223, 225, 834, 836, 838, 840.
Kill van Kull.......	26	4.07	70	403, 406, 409, 412, 844, 847, 850, 853, 1774, 1777, 1780, 1783, 1786, 1789, 1792, 1795, 1798, 1801, 1804, 1807, 1810, 1813, 1816, 1819, 1822, 1825.	26	4.26	73	404, 407, 410, 413, 845, 848, 851, 854, 1775, 1778, 1781, 1784, 1787, 1790, 1793, 1796, 1799, 1802, 1805, 1808, 1811, 1814, 1817, 1820, 1823, 1826.	26	4.29	74	405, 408, 411, 414, 846, 849, 852, 855, 1776, 1779, 1782, 1785, 1788, 1791, 1794, 1797, 1800, 1803, 1806, 1809, 1812, 1815, 1818, 1821, 1824, 1827.
The Narrows.......	56	4.37	76	358, 382, 876, 879, 882, 885, 888, 891, 894, 897, 900, 1474, 1477, 1480, 1483, 1486, 1489, 1492, 1495, 1498, 1501, 1504, 1507, 1510, 1513, 1516, 1519, 1522, 1525, 1528, 1531, 1534, 1537, 1540, 1543, 1546, 1549, 1552, 1555, 1558, 1561, 1564, 1567, 1570, 1573, 1576, 2095, 2110, 2125, 2140, 2155, 2170, 2245, 2248, 2287, 2290.	56	4.48	79	359, 383, 877, 880, 883, 886, 889, 892, 895, 898, 901, 1475, 1478, 1481, 1484, 1487, 1490, 1493, 1496, 1499, 1502, 1505, 1508, 1511, 1514, 1517, 1520, 1523, 1526, 1529, 1532, 1535, 1538, 1541, 1544, 1547, 1550, 1553, 1556, 1559, 1562, 1565, 1568, 1571, 1574, 1577, 2096, 2111, 2126, 2141, 2156, 2171, 2246, 2249, 2288, 2291.	56	4.48	79	360, 384, 878, 881, 884, 887, 890, 893, 896, 899, 902, 1476, 1479, 1482, 1485, 1488, 1491, 1494, 1497, 1500, 1503, 1506, 1509, 1512, 1515, 1518, 1521, 1524, 1527, 1530, 1533, 1536, 1539, 1542, 1545, 1548, 1551, 1554, 1557, 1560, 1563, 1566, 1569, 1572, 1575, 1578, 2097, 2112, 2127, 2142, 2157, 2172, 2247, 2250., 2289, 2291.
Gowanus canal.....	12	1.74	32	12, 14, 16, 18, 128, 131, 133, 135, 690, 692, 948, 951.	10	1.97	36	13, 15, 17, 19, 129, 132, 134, 136, 949, 951.	3	2.31	43	130, 691, 693.
Newtown creek.....	4	1.14	17	2319, 2321, 2323, 2325.	—	—	—	No mid-depth samples.	4	1.14	17	2320, 2322, 2324, 2326.
Wallabout canal....	1	1.67	30	2279.	—	—	—	No mid-depth samples.	1	1.67	30	2280.
Long Island Sound.	8	5.32	94	700, 703, 722, 725, 961, 964, 2309, 2333.	7	4.42	93	701, 704, 723, 726, 962, 965, 2310.	7	4.42	93	702, 705, 724, 727, 963, 966, 2311.
Newark bay........	38	3.93	63	415, 856, 858, 860, 862, 864, 866, 1828, 1830, 1833, 1835, 1837, 1839, 1841, 1844, 1846, 1848, 1850, 1852, 1855, 1857, 1859, 1861, 1863, 1866, 1868, 1870, 1872, 1874, 1877, 1879, 1881, 1883, 1885, 1888, 1890, 1892, 2335.	8	3.90	64	416, 863, 1831, 1842, 1853, 1864 1875, 1886.	36	3.93	63	417, 857, 859, 861, 865, 867, 1829, 1832, 1834, 1836, 1838, 1840, 1843, 1845, 1847, 1849, 1851, 1854, 1856, 1858, 1860, 1862, 1865, 1867, 1869, 1871, 1873, 1876, 1878, 1880, 1882, 1884, 1887, 1889, 1891, 1893.
Passaic river, near Newark..........	4	0.00	0	868, 870, 872, 874.	—	—	—	No mid-depth samples.	4	0.00	0	869, 871, 873, 875.
Lower bay.........	20	5.49	97	361, 364, 385, 388, 391, 394, 734, 736, 738, 740, 742, 744, 746, 748, 750, 752, 764, 766, 2340, 2341.	6	5.16	94	362, 365, 386, 389, 392, 395.	18	5.35	98	363, 366, 387, 390, 393, 396, 735, 737, 739, 741, 743, 745, 749, 751, 753, 765, 767.

TABLE CXVII—Continued

Location	Depths											
	Surface				Mid-depth				Bottom			
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Buttermilk channel.	23	2.70	50	3, 6, 9, 230, 233, 240, 247, 250, 253, 323, 326, 333, 336, 340, 343, 658, 661, 668, 671, 674, 677, 684, 687.	22	3.00	56	4, 7, 10, 231, 234, 241, 248, 251, 254, 324, 327, 334, 341, 344, 659, 662, 669, 672, 675, 678, 685, 688.	23	3.03	59	5, 8, 11, 232, 235, 242, 249, 252, 255, 325, 328, 335, 337, 342, 345, 660, 663, 670, 673, 676, 679, 686, 689.
Manhasset bay.....	8	5.24	97	706, 708, 710, 712, 714, 716, 718, 720.	—	—	—	No mid-depth samples.	8	5.24	97	707, 709, 711, 713, 715, 717, 719, 721.
Cheesequake creek..	5	5.44	100	754, 756, 758, 760, 762.	—	—	—	No mid-depth samples.	5	5.44	100	755, 757, 759, 761, 763.
Atlantic ocean.....	3	5.66	100	367, 370, 397.	3	5.66	100	368, 371, 398.	3	5.66	100	369, 372, 399.

TABLE CXVIII

Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1911

Averages of samples taken on Ebb and Flood Currents for various parts of the harbor

Data for this table are contained in Table XXVII, Report of Metropolitan Sewerage Commission, 1912.

Location	Currents							
	Ebb Currents				Flood Currents			
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Upper bay	102	4.29	72	92–94, 260–269, 349–357, 841–843, 2038–2047, 2050, 2053, 2098–2109, 2113–2124, 2143–2154, 2158–2169, 2251–2265, 2276, 2339.	93	4.43	73	110–112, 270–274, 373–381, 400–402, 2048–2049, 2051–2052, 2054–2094, 2128–2139, 2230–2244, 2275.
Hudson river, below Spuyten Duyvil	246	3.51	62	20–22, 137–169, 278–310, 463–492, 538–551, 556–588, 918–947, 1579–1608, 1654–1683, 2266–2274, 2336.	99	3.36	59	275–277, 493–522, 903–917, 1609–1653, 2227–2229, 2316–2318.
Hudson river, above Spuyten Duyvil	113	5.06	81	38–52, 170–181, 311–322, 352–355, 589–597, 1948–1977, 2008–2037, 2337.	45	4.55	71	23–37, 1978–2007.
East river, below Hell Gate	115	2.96	53	95–106, 613–642, 768–782, 815–816, 821–822, 825–828, 952–954, 1684–1698, 1744–1773, 2338, 2342.	102	3.17	57	113–124, 598–612, 783–812, 1699–1743.
East river, above Hell Gate	115	4.45	77	68–91, 107–109, 643–657, 728–733, 955–960, 1921–1947, 2173–2181, 2200, 2209–2226, 2301–2303, 2306–2308.	138	3.60	62	53–67, 125–127, 418–462, 523–537, 694–699, 1894–1920, 2182–2199, 2201–2208, 2334.
Harlem river	22	2.06	38	182–203.	30	2.43	46	204–225, 833–840.
Kill van Kull	30	4.16	72	844–855, 1783–1800.	48	4.25	73	403–414, 1774–1782, 1801–1827.
The Narrows	118	4.22	74	358–360, 876–902, 1474–1485, 1519–1578, 2110–2112, 2125–2127, 2155–2157, 2170–2172, 2248–2250, 2287.	50	4.94	86	382–384, 1486–1518, 2095–2097, 2140–2142, 2245–2247, 2288–2292.
Gowanus canal	4	1.68	31	948–951.	21	1.94	35	12–19, 128–136, 690–693.
Newtown creek	—	—	—	No samples on ebb current.	8	1.14	17	2319–2396.
Wallabout canal	—	—	—	No samples on ebb current.	2	1.67	30	2279–2280.
Long Island Sound	15	4.70	94	722–727, 961–966, 2309–2311.	7	5.12	92	700–705, 2333.
Newark bay	40	3.90	64	856–867, 1828–1830, 1833–1843, 1859–1871, 2335.	42	3.94	63	415–417, 1831–1832, 1844–1858, 1872–1893.
Passaic river, near Newark	8	0.00	0	868–875.	—	—	—	No samples on flood current.
Lower bay	8	5.04	87	361–366, 2340–2341.	36	5.46	99	385–396, 734–753, 764–767.
Buttermilk channel	39	2.79	52	3–11, 230–235, 240–242, 247–255, 674–679, 684–689.	29	3.07	58	323–328, 333–337, 340–345, 658–663, 668–673.
Manhasset bay	8	5.09	95	706–713.	8	5.41	99	714–721.
Cheesequake creek	—	—	—	No samples on ebb current.	10	5.44	100	754–763.
Atlantic ocean	6	5.61	100	367–372.	3	5.76	100	397–399.

TABLE CXIX

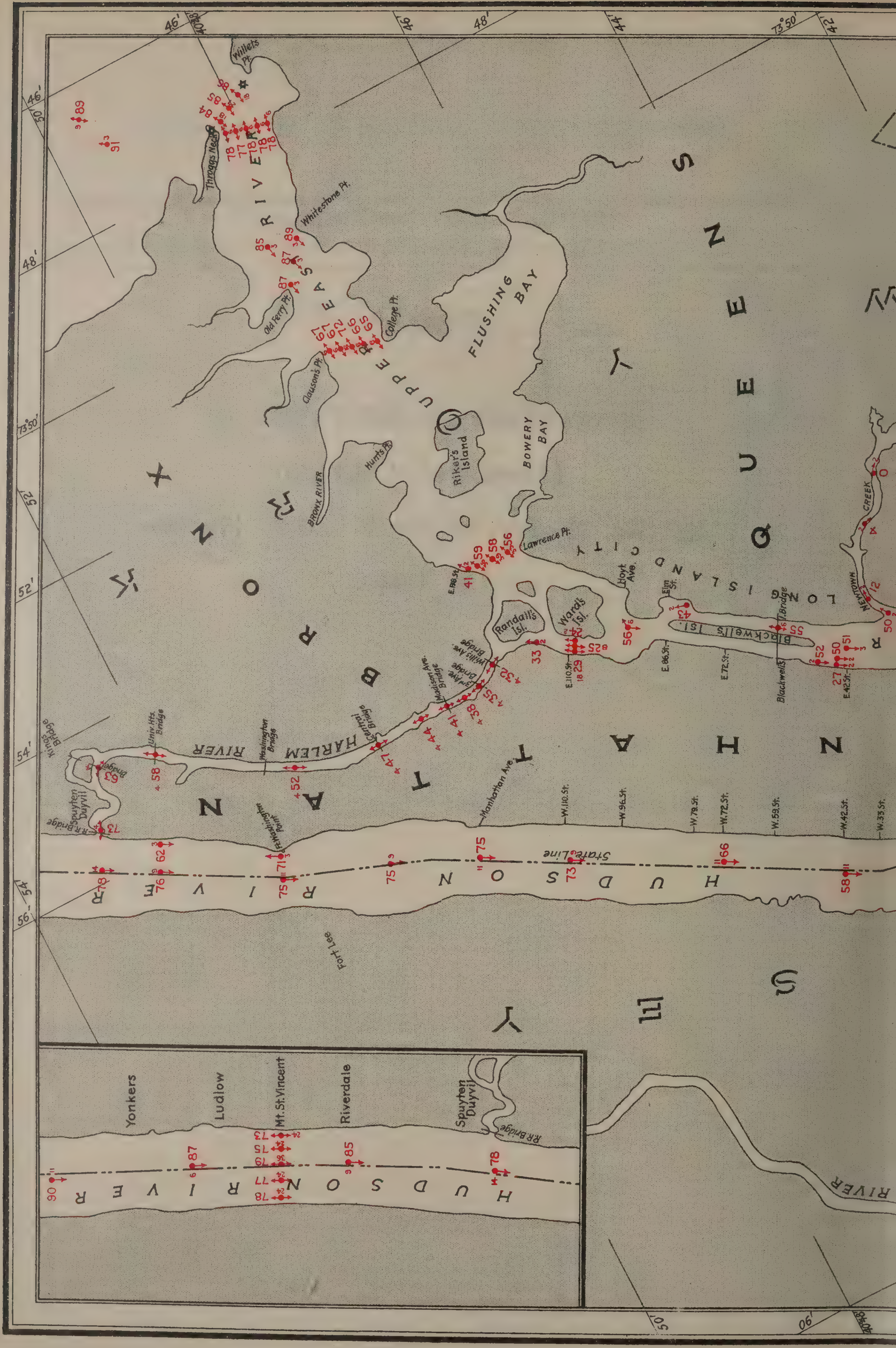
Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1911
Summary of Tables CXVI, CXVII and CXVIII

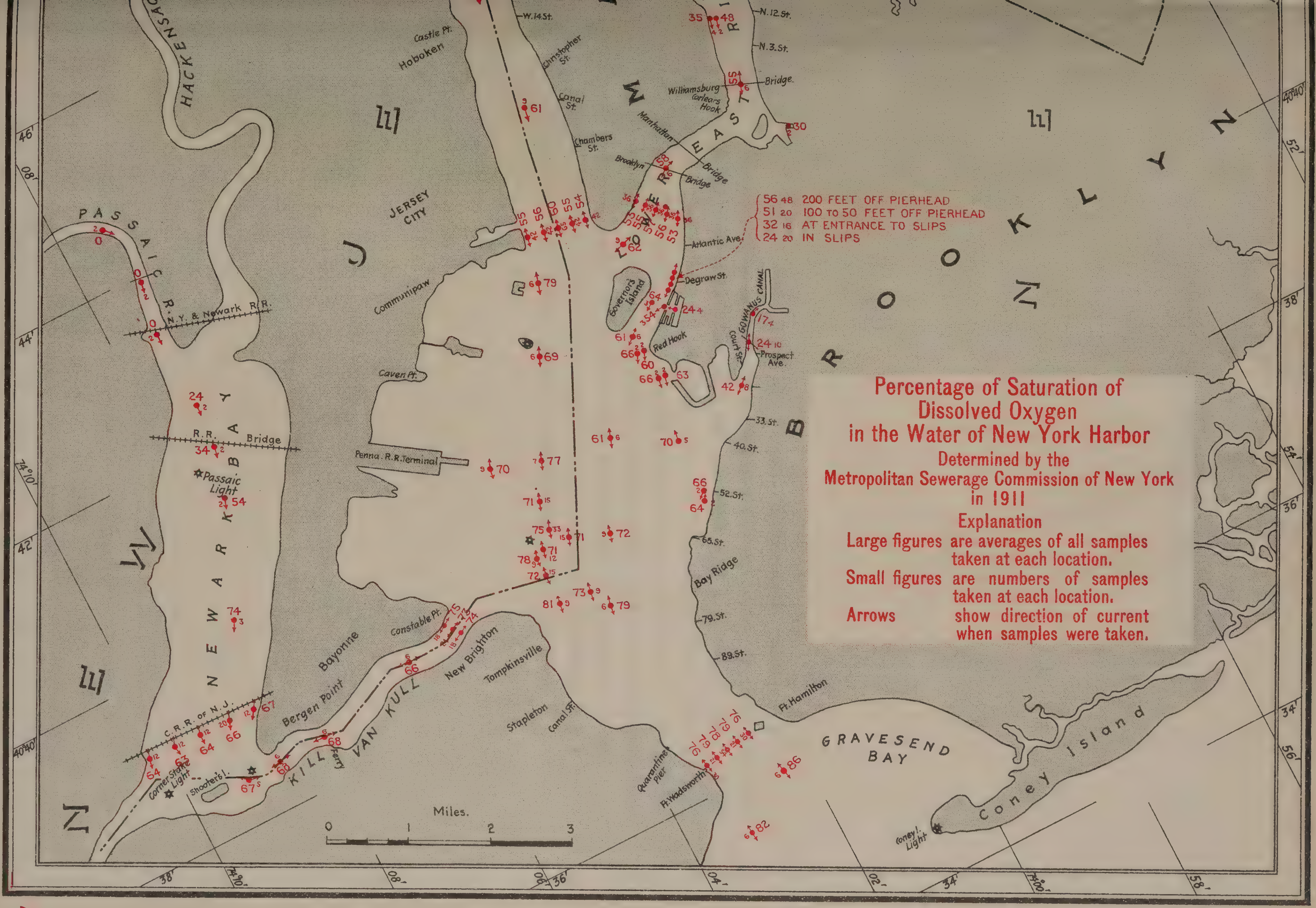
Data for this table are contained in Table XXVII, Report of Metropolitan Sewerage Commission, 1912.

Location	All Depths and Tides			Depths									Currents					
				Surface			Mid-depth			Bottom			Ebb			Flood		
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation
Upper bay	195	4.35	73	68	3.93	71	60	4.48	75	67	4.68	73	102	4.29	72	93	4.43	73
Hudson river, below Spuyten Duyvil	345	3.47	61	119	3.53	62	109	3.38	60	117	3.47	62	246	3.51	62	99	3.36	59
Hudson river, above Spuyten Duyvil	158	4.91	78	54	5.18	82	51	4.78	76	53	4.76	67	113	5.06	81	45	4.55	71
East river, below Hell Gate	217	3.06	55	75	3.04	54	73	3.06	55	69	3.08	55	115	2.96	53	102	3.17	57
East river, above Hell Gate	253	3.99	69	85	4.00	69	84	3.99	69	84	3.98	69	115	4.45	77	138	3.60	62
Harlem river	52	2.28	43	26	2.27	42	—	—	—	26	2.28	43	22	2.06	38	30	2.43	46
Kill van Kull	78	4.19	72	26	4.07	70	26	4.26	73	26	4.29	74	30	4.16	72	48	4.25	73
The Narrows	168	4.43	78	56	4.37	76	56	4.48	79	56	4.48	79	118	4.22	74	50	4.94	86
Gowanus canal	25	1.90	20	12	1.74	32	10	1.97	36	3	2.31	43	4	1.68	31	21	1.94	35
Newtown creek	8	1.14	17	4	1.14	17	—	—	—	4	1.14	17	—	—	—	8	1.14	17
Wallabout canal	2	1.67	30	1	1.67	30	—	—	—	1	1.67	30	—	—	—	2	1.67	30
Long Island Sound	22	4.74	93	8	5.32	94	7	4.42	93	7	4.42	93	15	4.70	94	7	5.12	92
Newark bay	82	3.92	63	38	3.93	63	8	3.90	64	36	3.93	63	40	3.90	64	42	3.94	63
Passaic river, near Newark	8	0.00	0	4	0.00	0	—	—	—	4	0.00	0	8	0.00	0	—	—	—
Lower bay	44	5.39	97	20	5.49	97	6	5.16	94	18	5.35	98	8	5.04	87	36	5.46	99
Buttermilk channel	68	2.91	54	23	2.70	50	22	3.00	56	23	3.03	59	39	2.79	52	29	3.07	58
Manhasset bay	16	5.24	97	8	5.24	97	—	—	—	8	5.24	97	8	5.09	95	8	5.41	99
Cheesequake creek	10	5.44	100	5	5.44	100	—	—	—	5	5.44	100	—	—	—	10	5.44	100
Atlantic ocean	9	5.66	100	3	5.66	100	3	5.66	100	3	5.66	100	6	5.61	100	3	5.76	100

Plate A

Percentage of Saturation of Dissolved Oxygen in the Water of New York Harbor in 1911


BRONX
QUEENS
MANHATTAN
UPPER EAST RIVER
HARLEM RIVER
HUDSON RIVER
FLUSHING BAY
BOWERY BAY
Riker's Island
Randall's Isl.
Ward's Isl.
Blackwell's Isl.
LONG ISLAND CITY
NEWTOWN CREEK
Throggs Neck
Willets Pt.
Whitestone Pt.
Old Ferry Pt.
Clauson's Pt.
College Pt.
Hunt's Pt.
BRONX RIVER
Lawrence Pt.
Hoyt Ave.
Elm St.
E.88 St.
E.110 St.
E.86 St.
E.72 St.
E.42 St.
Blackwell's I. Bridge
Willis Ave. Bridge
3rd Ave. Bridge
Madison Ave. Bridge
Central Bridge
Washington Bridge
Univ. Hts. Bridge
Kings Bridge
Spuyten Duyvil
R.R. Bridge
Ft. Washington Point
Manhattan Ave.
W.110 St.
W.96 St.
W.79 St.
W.72 St.
W.59 St.
W.42 St.
W.33 St.
State Line
Fort Lee
Yonkers
Ludlow
Mt. St. Vincent
Riverdale
73°50'
40°48'



Percentage of Saturation of Dissolved Oxygen in the Water of New York Harbor

Determined by the Metropolitan Sewerage Commission of New York in 1911

Explanation

Large figures are averages of all samples taken at each location.

Small figures are numbers of samples taken at each location.

Arrows show direction of current when samples were taken.

56 48 200 FEET OFF PIERHEAD
51 20 100 TO 50 FEET OFF PIERHEAD
32 16 AT ENTRANCE TO SLIPS
24 20 IN SLIPS

A

INTRODUCTION TO TABLES CXX, CXXI, CXXII, CXXIII, CXXIV

The analyses for oxygen made in the year 1912 were made in the same manner and by the same persons as in the years 1909 and 1911. The total number taken was less than in either of the two previous years, and the averages shown in Tables CXXI, CXXII, CXXIII and CXXIV may not be as truly representative of mean conditions as those obtained in other years and from a larger number of samples. The results found from analyses made at various localities, depths and tides have been computed from data contained in Table CXX, and are given in Tables CXXI, CXXII and CXXIII. In Table CXXIV is given a summary of the results of these calculations.

TABLE CXX

VOLUME AND PERCENTAGE OF SATURATION OF DISSOLVED OXYGEN IN THE WATER IN THE YEAR 1912

Table of Contents

Section No.	Location	Date of Collection	Page
1	East river, Hudson river, Upper bay and Narrows	Feb. 27, 1912	657
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6	Passaic river at West Arlington and at Newark, N. J.	Apr. 5, 1912	659
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14	Hudson river, Cross-section at Pier A	Sept. 13, 1912	662
15	East river, Cross-section below Brooklyn Bridge	Sept. 26, 1912	663
16	Cross-section of the Narrows	Oct. 4, 1912	664
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TABLE CXX

1—EAST RIVER, HUDSON RIVER, UPPER BAY AND NARROWS. FEBRUARY 27, 1912

High water occurred at Governors Island at 3.00 P. M. Low water at 11.10. The wind was northwest, with a ve o 40 miles per hour.

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1	10.30	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	2.2	24	6.57	80
2	10.40	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	3.3	24	6.57	80
3	11.30	Hudson river, midway between Pier A and C. R.R. of N. J. ferry	40 42 19	74 01 34	1	Ebb	2.8	34	6.57	80
4	11.40	Hudson river, midway between Pier A and C. R.R. of N. J. ferry	40 42 19	74 01 34	30	Ebb	2.8	34	6.57	80
5	P. M. 12.30	Narrows, midway between forts	40 36 25	74 02 48	1	End of Ebb	2.8	30	7.57	92
6	12.40	Narrows, midway between forts	40 36 25	74 02 48	60	Flood	3.3	16	7.71	98
7	1.15	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	End of Ebb	2.8	32	7.14	87
8	1.25	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Flood	2.8	28	7.28	89

2—EAST RIVER, HUDSON RIVER, UPPER BAY, NARROWS AND KILL VAN KULL. MARCH 4, 1912

High water occurred at Governors Island at 8.40 A. M. Low water at 3.15 P. M. The wind was east, with a velocity of 5 miles per hour.

9	A. M. 10.30	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	1.7	24	6.57	79
10	10.35	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	2.2	24	6.57	80
11	11.00	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	1.1	32	6.86	81
12	11.05	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Ebb	1.7	32	6.86	82
13	11.30	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Ebb	1.1	24	7.14	85
14	11.35	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Ebb	1.7	24	7.14	86
15	12.00	Kill van Kull, midstream, at Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	1.1	36	7.14	83
16	P. M. 12.05	Kill van Kull, midstream, at Sailors Snug Harbor	40 38 50	74 06 25	30	Ebb	1.7	36	7.14	84
17	1.00	The Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	1.1	22	7.43	88
18	1.05	The Narrows, midway between forts	40 36 25	74 02 48	60	Ebb	1.7	22	7.43	88

3—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. MARCH 5, 1912

High water occurred at Governors Island at 9.15 A. M. Low water at 3.45 A. M. The wind was southeast, with a velocity of 10 miles per hour.

19	A. M. 6.05	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	0.6	28	6.86	80
20	6.10	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	1.1	28	6.86	80
21	6.25	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Flood	0.6	32	7.00	81
22	6.30	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Flood	1.1	32	7.00	82

TABLE CXX—Continued

3—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. MARCH 5, 1912—Continued

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
23	7.00	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Flood	0.6	24	7.43	88
24	7.05	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Flood	1.1	24	7.43	89
25	7.30	Kill van Kull, midstream, at Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	0.6	24	7.14	84
26	7.35	Kill van Kull, midstream, at Sailors Snug Harbor	40 38 50	74 06 25	30	Flood	1.1	24	7.14	85
27	8.10	The Narrows, midway between forts	40 36 25	74 02 48	1	Flood	0.6	20	8.15	96
28	8.15	The Narrows, midway between forts	40 36 25	74 02 48	60	Flood	1.1	16	8.00	97

4—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. MARCH 14, 1912

High water occurred at Governors Island at 6.30 P. M. Low water at 12.20 A. M. The wind was southwest, light.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	C. C. per litre	Per cent. saturation
29	A. M. 11.15	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	4.4	40	6.43	80
30	11.20	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	4.4	40	6.43	80
31	11.50	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	3.3	84	6.86	76
32	12.00	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Ebb	3.9	44	6.43	80
33	P. M. 12.30	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Ebb	3.3	64	6.86	80
34	12.40	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Ebb	3.9	40	6.86	85
35	1.10	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	5.0	76	7.00	82
36	1.20	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	40	Ebb	5.0	56	6.86	85
37	1.50	The Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	3.9	64	7.43	88
38	2.00	The Narrows, midway between forts	40 36 25	74 02 48	60	Flood	3.9	32	7.57	95

5—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. APRIL 3, 1912

High water occurred at Governors Island at 9.20 A. M. Low water at 3.50 P. M. The wind was northwest, with a velocity of 30 miles per hour.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	C. C. per litre	Per cent. saturation
39	A. M. 8.50	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	6.1	72	6.71	82
40	9.00	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	6.1	68	6.57	81
41	9.30	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	5.6	88	7.43	85
42	9.40	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Flood	6.1	68	6.80	83
43	10.05	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Flood	6.1	64	7.28	90
44	10.15	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Flood	6.1	44	7.00	90
45	10.30	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	6.1	64	7.00	87
46	10.40	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	40	Flood	6.1	52	6.86	87
47	11.00	Narrows, midway between forts	40 36 25	74 02 48	1	Flood	6.1	56	7.71	97
48	11.10	Narrows, midway between forts	40 36 25	74 02 48	60	Flood	6.1	40	7.57	98

TABLE CXX—Continued

5—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. APRIL 3, 1912—Continued.

Sample No.	Hour P. M.	Location of Samples: Approximate	Location of Samples: Latitude	Location of Samples: Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen: C. C. per litre	Oxygen: Per cent. saturation
			° ′ ″	° ′ ″						
49	3.50	Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	6.1	84	7.43	88
50	4.00	Narrows, midway between forts	40 36 25	74 02 48	60	Ebb	6.1	68	7.14	87
51	4.30	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	6.1	80	7.28	86
52	4.40	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	40	Ebb	6.1	68	7.00	85
53	4.50	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Ebb	6.1	84	7.28	86
54	5.00	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Ebb	6.1	64	6.86	85
55	5.20	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	6.1	94	7.57	88
56	5.30	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Ebb	6.1	92	7.57	88
57	5.50	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	6.1	72	6.71	82
58	6.00	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	6.1	64	6.43	80

6—PASSAIC RIVER AT WEST ARLINGTON AND AT NEWARK, N. J. APRIL 5, 1912

High water occurred at Governors Island at 11.40 A. M. The wind was northwest, light.

A	M. 12.00	Passaic river, at Erie R.R. trestle, West Arlington, N. J.	40 45 18	74 09 55	Surface	Slack	10.0	100	7.00	88
B	P. M. 1.30	Passaic river, about 100 yards below Penn. R.R. passenger bridge	40 44 48	74 09 56	Surface	Slack	10.0	100	4.14	52

7—HUDSON RIVER AND EAST RIVER. APRIL 16, 1912

Low water occurred at Governors Island at 1.30 P. M. The wind was northwest, light.

59	A. M. 10.30	Hudson river, off end of Pier A	40 42 16	74 01 09	Surface	Ebb	10.0	60	6.49	88
60	11.30	East river, off end of Pier 4	40 42 01	74 00 38	Surface	Ebb	10.0	52	5.71	79

8—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND THE NARROWS. JUNE 13, 1912

High water occurred at Governors Island at 7.00 P. M. Low water at 1.10 P. M. The wind was northwest, with a velocity of 35 miles per hour.

61	A. M. 10.10	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	17.2	32	3.88	65
62	10.15	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	16.7	30	3.88	64
63	10.30	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	1	Ebb	17.2	40	4.49	74
64	10.40	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	30	Ebb	17.2	38	4.39	74
65	11.15	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Ebb	17.2	32	4.19	70
66	11.20	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Ebb	16.7	30	4.19	69
67	11.30	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	17.2	40	4.29	70
68	11.35	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	40	Ebb	17.2	40	4.29	70
69	11.55	Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	17.2	32	4.29	71
70	12.00	Narrows, midway between forts	40 36 25	74 02 48	60	Ebb	16.7	30	4.39	73

TABLE CXX—Continued

9—THE NARROWS, KILL VAN KULL, UPPER BAY, HUDSON RIVER AND EAST RIVER. JUNE 13, 1912

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
71	2.30	Narrows, midway between forts	40 36 25	74 02 48	1	Flood	17.2	32	4.80	80
72	2.35	Narrows, midway between forts	40 36 25	74 02 48	60	Flood	16.7	32	4.90	81
73	3.10	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	17.2	36	4.39	73
74	3.15	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	40	Flood	16.7	36	4.39	71
75	3.40	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Flood	17.2	30	4.29	71
76	3.45	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Flood	16.7	30	4.29	71
77	4.10	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	1	Flood	17.2	38	4.19	69
78	4.15	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	30	Flood	16.7	36	4.19	68
9	4.30	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	17.2	34	3.68	60
80	4.35	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	16.7	32	3.68	61

10—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. JULY 11, 1912

High water occurred at Governors Island at 5.30 P. M. Low water at 11.55 A. M. The wind was southwest, with a velocity of 10 miles per hour.

81	A. M. 9.00	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	23.6	24	2.40	46
82	9.10	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	23.6	24	2.40	46
83	9.30	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	23.9	36	2.90	54
84	9.40	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Ebb	23.6	36	2.80	52
85	10.10	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Ebb	23.9	26	3.00	57
86	10.15	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Ebb	23.6	26	3.10	59
87	10.30	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	23.9	30	3.10	58
88	10.40	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	40	Ebb	23.9	30	3.10	58
89	11.15	The Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	23.9	26	3.20	61
90	11.25	The Narrows, midway between forts	40 36 25	74 02 48	60	Ebb	23.6	24	3.30	63
91	P. M. 1.30	The Narrows, midway between forts	40 36 25	74 02 48	1	Flood	23.9	22	3.90	75
92	1.35	The Narrows, midway between forts	40 36 25	74 02 48	60	Flood	23.6	22	4.00	77
93	2.00	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	23.9	26	3.20	61
94	2.05	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	40	Flood	23.9	26	3.20	61
95	2.30	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Flood	23.9	24	3.50	67
96	2.35	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Flood	23.6	24	3.50	67
97	3.05	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Flood	23.9	26	3.00	57
98	3.10	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Flood	23.9	26	3.10	59
99	3.30	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	23.9	24	2.60	50
100	3.35	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	23.9	24	2.60	50

TABLE CXX—Continued

11—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. JULY 24, 1912

High water occurred at Governors Island at 5.30 P. M. Low water at 10.40 A. M. The wind was northwest, with a velocity of 10 miles per hour.

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
101	9.30	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	21.7	22	2.50	46
102	9.35	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	21.7	22	2.50	46
103	10.00	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	21.7	34	3.10	55
104	10.05	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Ebb	21.7	30	3.00	55
105	10.35	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Ebb	21.7	24	2.90	53
106	10.40	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Ebb	21.7	24	2.90	53
107	11.15	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	21.7	32	3.40	61
108	11.20	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	40	Ebb	21.7	32	3.30	60
109	11.45	The Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	21.7	22	3.40	62
110	11.50	The Narrows, midway between forts	40 36 25	74 02 48	60	Ebb	21.7	20	3.40	62
111	P. M. 1.50	The Narrows, midway between forts	40 36 25	74 02 48	1	Flood	21.7	20	3.90	71
112	1.55	The Narrows, midway between forts	40 36 25	74 02 48	60	Flood	21.1	18	4.00	73
113	2.25	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	21.7	24	3.80	69
114	2.30	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 25	40	Flood	21.7	24	3.80	69
115	2.50	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Flood	21.7	22	3.60	65
116	2.55	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Flood	21.1	22	3.70	67
117	3.15	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	21.7	34	3.70	66
118	3.20	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Flood	21.1	26	3.70	67
119	3.40	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	21.7	30	2.80	50
120	3.45	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	21.1	24	2.80	51

12—GOWANUS CANAL AND DEGRAW STREET SLIP, BROOKLYN. AUGUST 13, 1912

High water occurred at Governors Island at 8.30 A. M. Low water at 3.00 P. M. The wind was south, light.

121	A. M. 11.00	Slip at foot of Degraw St., Brooklyn	40 41 13	74 00 25	Surface	Ebb	25.0	28	0.40	8
122	11.45	Gowanus canal at Hamilton avenue bridge	40 40 17	73 59 56	Surface	Flood	25.0	20	1.80	35
123	P. M. 12.30	Gowanus canal, at head of canal, foot of Douglas street, at pumping station	40 40 55	73 59 15	Surface	Slack	26.7	72	0.00	0
124	1.00	Gowanus canal at Union street bridge	40 40 25	73 59 50	Surface	Flood	26.7	28	0.00	0
125	1.30	Slip just east of Degraw street slip	40 41 16	74 00 30	Surface	Ebb	25.6	24	1.20	23
126	2.00	Slip at foot of Degraw street, Brooklyn	40 41 13	74 00 25	Surface	Ebb	25.6	28	0.20	4

13—SLIPS IN HUDSON RIVER AND IN HARLEM RIVER. AUGUST 16, 1912

High water occurred at Governors Island at 11.20 A. M. Low water at 6.00 P. M. The wind was northwest, light.

127	M. 12.00	Slip south of pier foot of East 109th street, Harlem river	40 47 24	73 56 11	Surface	Flood	23.3	24	0.50	9
128	P. M. 12.45	Slip south of pier foot of West 129th street, Hudson river	40 49 04	73 57 43	Surface	Flood	23.3	40	2.00	36

TABLE CXX—Continued

13—SLIPS IN HUDSON RIVER AND IN HARLEM RIVER. AUGUST 16, 1912—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
129	1.30	Slip south of pier foot of West 41st street, Hudson river...............	40 45 40	74 00 08	Surface	Ebb	23.6	36	1.80	33
130	2.00	Slip north of pier foot of West 34th street, Hudson river...............	40 45 25	74 00 23	Surface	Ebb	23.6	34	1.60	30
131	2.35	Slip foot of Gansevoort street, Hudson river............................	40 44 19	74 00 40	Surface	Ebb	23.3	32	1.90	35
132	3.00	Slip foot of Canal street, Hudson river	40 43 34	74 00 43	Surface	Ebb	23.6	32	1.40	26

14—CROSS-SECTION OF HUDSON RIVER AT PIER A. SEPTEMBER 13, 1912

High water occurred at Governors Island at 10.00 A. M. Low water at 4.15 P. M. The wind was south, light.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	C. C. per litre	Per cent. saturation
133	A. M. 9.25	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	1	Flood	21.1	26	3.10	56
134	9.27	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	20	Flood	21.1	24	3.20	58
135	9.30	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	40	Flood	21.1	24	3.20	58
136	9.35	¼ way across......................	40 42 17	74 01 20	1	Flood	21.1	26	2.90	53
137	9.37	¼ way across......................	40 42 17	74 01 20	20	Flood	21.1	24	3.20	58
138	9.40	¼ way across......................	40 42 17	74 01 20	40	Flood	21.1	24	3.30	60
139	9.45	½ way across......................	40 42 19	74 01 34	1	Flood	21.1	26	3.00	55
140	9.47	½ way across......................	40 42 19	74 01 34	20	Flood	21.1	24	3.30	60
141	9.50	½ way across......................	40 42 19	74 01 34	40	Flood	21.1	24	3.40	62
142	9.55	¾ way across......................	40 42 19	74 01 48	1	Flood	21.1	26	2.60	48
143	9.57	¾ way across......................	40 42 19	74 01 48	20	Flood	21.1	24	3.30	60
144	10.00	¾ way across......................	40 42 19	74 01 48	35	Flood	21.1	24	3.40	62
145	10.05	200 feet off C. R.R. of N. J. ferry, Communipaw........................	40 42 22	74 01 59	1	Flood	21.1	28	2.70	50
146	10.07	200 feet off C. R.R. of N. J. ferry, Communipaw........................	40 42 22	74 01 59	15	Flood	21.1	26	3.30	60
147	10.10	200 feet off C. R.R. of N. J. ferry, Communipaw........................	40 42 22	74 01 59	30	Flood	21.1	26	3.40	62
148	P. M. 12.40	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	1	Ebb	21.1	26	3.00	55
149	12.42	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	20	Ebb	21.1	24	3.30	60
150	12.45	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	40	Ebb	21.1	24	3.40	62
151	12.50	¼ way across......................	40 42 17	74 01 20	1	Ebb	21.1	26	2.80	51
152	12.52	¼ way across......................	40 42 17	74 01 20	20	Ebb	21.1	24	3.20	58
153	12.55	¼ way across......................	40 42 17	74 01 20	40	Ebb	21.1	24	3.30	60
154	1.00	½ way across......................	40 42 19	74 01 34	1	Ebb	21.1	26	3.00	55
155	1.02	½ way across......................	40 42 19	74 01 34	20	Ebb	21.1	26	3.30	60
156	1.05	½ way across......................	40 42 19	74 01 34	40	Ebb	21.1	26	3.30	60
157	1.10	¾ way across......................	40 42 19	74 01 48	1	Ebb	21.1	28	3.00	55
158	1.12	¾ way across......................	40 42 19	74 01 48	20	Ebb	21.1	26	3.10	56
159	1.15	¾ way across......................	40 42 19	74 01 48	35	Ebb	21.1	26	3.10	56
160	1.20	200 feet off C. R.R. of N. J. ferry, Communipaw........................	40 42 22	74 01 59	1	Ebb	21.1	28	2.90	53
161	1.22	200 feet off C. R.R. of N. J. ferry, Communipaw........................	40 42 22	74 01 59	15	Ebb	21.1	26	3.10	56
162	1.25	200 feet off C. R.R. of N. J. ferry, Communipaw........................	40 42 22	74 01 59	30	Ebb	21.1	26	3.10	56
163	2.45	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	1	Ebb	21.1	28	2.90	53
164	2.47	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	20	Ebb	21.1	26	3.10	56
165	2.50	200 feet off Pier A, Manhattan.......	40 42 16	74 01 10	40	Ebb	21.1	26	3.10	56
166	3.00	¼ way across......................	40 42 17	74 01 20	1	Ebb	21.1	28	2.80	51

TABLE CXX—Continued

14—CROSS SECTION OF HUDSON RIVER AT PIER A. SEPTEMBER 13, 1912—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
167	3.02	¼ way across	40 42 17	74 01 20	20	Ebb	21.1	26	3.10	56
168	3.05	¼ way across	40 42 17	74 01 20	40	Ebb	21.1	26	3.10	56
169	3.10	½ way across	40 42 19	74 01 34	1	Ebb	21.1	28	2.80	51
170	3.12	½ way across	40 42 19	74 01 34	20	Ebb	21.1	26	3.10	56
171	3.15	½ way across	40 42 19	74 01 34	40	Ebb	21.1	26	3.20	58
172	3.20	¾ way across	40 42 19	74 01 48	1	Ebb	21.1	30	2.80	51
173	3.22	¾ way across	40 42 19	74 01 48	20	Ebb	21.1	28	3.00	55
174	3.25	¾ way across	40 42 19	74 01 48	35	Ebb	21.1	28	3.10	56
175	3.35	200 feet off C. R.R. of N. J. pier, Communipaw	40 42 22	74 01 59	1	Ebb	21.1	30	2.70	50
176	3.37	200 feet off C. R.R. of N. J. pier, Communipaw	40 42 22	74 01 59	15	Ebb	21.1	28	3.00	55
177	3.40	200 feet off C. R.R. of N. J. pier, Communipaw	40 42 22	74 01 59	30	Ebb	21.1	28	3.00	55

15—CROSS SECTION OF EAST RIVER BELOW BROOKLYN BRIDGE. SEPTEMBER 26, 1912

High water occurred at Governors Island at 9.15 A. M. Low water at 3.50 P. M. The wind was east, light.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	C. C. per litre	Per cent. saturation
	A. M.									
178	8.10	200 feet off Pier 10, New York	40 42 09	74 00 22	1	Flood	18.9	26	2.94	52
179	8.12	200 feet off Pier 10, New York	40 42 09	74 00 22	20	Flood	18.9	24	3.02	53
180	8.15	200 feet off Pier 10, New York	40 42 09	74 00 22	30	Flood	18.9	24	3.08	54
181	8.20	¼ way across	40 42 07	74 00 17	1	Flood	18.9	26	2.74	48
182	8.22	¼ way across	40 42 07	74 00 17	20	Flood	18.9	24	2.76	48
183	8.25	¼ way across	40 42 07	74 00 17	40	Flood	18.9	24	3.04	53
184	8.30	½ way across	40 42 03	74 00 11	1	Flood	18.9	24	2.84	50
185	8.32	½ way across	40 42 03	74 00 11	20	Flood	18.9	24	2.89	51
186	8.35	½ way across	40 42 03	74 00 11	40	Flood	18.9	24	3.00	53
187	8.40	¾ way across	40 42 00	74 00 05	1	Flood	18.9	24	2.80	49
188	8.42	¾ way across	40 42 00	74 00 05	20	Flood	18.9	24	2.91	51
189	8.45	¾ way across	40 42 00	74 00 05	35	Flood	18.9	24	2.97	52
190	8.50	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Flood	18.9	24	2.82	49
191	8.52	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	20	Flood	18.9	24	2.90	51
192	8.55	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	35	Flood	18.9	24	2.88	51
193	10.30	200 feet off Pier 10, New York	40 42 09	74 00 22	1	Ebb	19.4	24	2.99	52
194	10.32	200 feet off Pier 10, New York	40 42 09	74 00 22	20	Ebb	18.9	24	3.04	53
195	10.35	200 feet off Pier 10, New York	40 42 09	74 00 22	30	Ebb	18.9	24	3.03	53
196	10.40	¼ way across	40 42 07	74 00 17	1	Ebb	19.4	24	2.81	49
197	10.42	¼ way across	40 42 07	74 00 17	20	Ebb	18.9	24	2.85	50
198	10.45	¼ way across	40 42 07	74 00 17	40	Ebb	18.9	24	3.04	53
199	10.50	½ way across	40 42 03	74 00 11	1	Ebb	19.4	24	2.82	49
200	10.52	½ way across	40 42 03	74 00 11	20	Ebb	18.9	24	2.90	51
201	10.55	½ way across	40 42 03	74 00 11	40	Ebb	18.9	24	2.89	51
202	11.00	¾ way across	40 42 00	74 00 05	1	Ebb	19.4	24	2.89	51
203	11.02	¾ way across	40 42 00	74 00 05	20	Ebb	18.9	24	3.01	52
204	11.05	¾ way across	40 42 00	74 00 05	35	Ebb	18.9	24	2.87	51
205	11.10	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Ebb	19.4	24	2.80	49
206	11.12	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	20	Ebb	18.9	24	2.82	49
207	11.15	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	35	Ebb	18.9	24	2.78	49
	P. M.									
208	1.00	200 feet off Pier 10, New York	40 42 09	74 00 22	1	Ebb	20.0	24	2.39	43
209	1.02	200 feet off Pier 10, New York	40 42 09	74 00 22	20	Ebb	19.4	24	2.43	43
210	1.05	200 feet off Pier 10, New York	40 42 09	74 00 22	30	Ebb	19.4	24	2.52	45

TABLE CXX—Continued

15—CROSS SECTION OF EAST RIVER BELOW BROOKLYN BRIDGE. SEPTEMBER 26, 1912—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
211	1.10	¼ way across	40 42 07	74 00 17	1	Ebb	20.0	24	2.43	43
212	1.12	¼ way across	40 42 07	74 00 17	20	Ebb	19.4	24	2.36	42
213	1.15	¼ way across	40 42 07	74 00 17	40	Ebb	19.4	24	2.43	43
214	1.20	½ way across	40 42 03	74 00 11	1	Ebb	20.0	24	2.42	43
215	1.22	½ way across	40 42 03	74 00 11	20	Ebb	19.4	24	2.50	45
216	1.25	½ way across	40 42 03	74 00 11	40	Ebb	19.4	24	2.50	45
217	1.30	¾ way across	40 42 00	74 00 05	1	Ebb	20.0	24	2.40	43
218	1.32	¾ way across	40 42 00	74 00 05	20	Ebb	20.0	24	2.49	44
219	1.35	¾ way across	40 42 00	74 00 05	35	Ebb	19.4	24	2.48	44
220	1.40	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Ebb	20.0	24	2.40	43
221	1.42	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	20	Ebb	20.0	24	2.42	43
222	1.45	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	35	Ebb	20.0	24	2.40	43

16—CROSS SECTION OF THE NARROWS. OCTOBER 4, 1912

High water occurred at Governors Island at 2.35 P. M. Low water at 9.50 A. M. The wind was southwest, moderate.

	A. M.									
223	8.00	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Ebb	17.2	26	4.42	75
224	8.02	200 feet off Fort Lafayette	40 36 29	74 02 24	20	Ebb	17.2	24	4.60	78
225	8.05	200 feet off Fort Lafayette	40 36 29	74 02 24	40	Ebb	17.2	24	4.70	80
226	8.10	¼ way across	40 36 27	74 02 34	1	Ebb	17.2	26	4.40	75
227	8.12	¼ way across	40 36 27	74 02 34	30	Ebb	17.2	24	4.57	77
228	8.15	¼ way across	40 36 27	74 02 34	60	Ebb	17.2	24	4.70	80
229	8.20	½ way across	40 36 25	74 02 48	1	Ebb	17.2	26	4.42	75
230	8.22	½ way across	40 36 25	74 02 48	30	Ebb	17.2	24	4.54	77
231	8.25	½ way across	40 36 25	74 02 48	60	Ebb	17.2	24	4.74	80
232	8.30	¾ way across	40 36 23	74 03 02	1	Ebb	17.2	26	4.35	74
233	8.32	¾ way across	40 36 23	74 03 02	30	Ebb	17.2	24	4.40	75
234	8.35	¾ way across	40 36 23	74 03 02	60	Ebb	17.2	24	4.48	76
235	8.40	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Ebb	17.2	26	4.18	71
236	8.42	200 feet off Fort Wadsworth	40 36 21	74 03 12	30	Ebb	17.2	24	4.40	75
237	8.45	200 feet off Fort Wadsworth	40 36 21	74 03 12	60	Ebb	17.2	24	4.47	76
238	10.30	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Slack	17.2	26	4.02	68
239	10.32	200 feet off Fort Lafayette	40 36 29	74 02 24	20	1st Flood	17.5	24	4.20	71
240	10.35	200 feet off Fort Lafayette	40 36 29	74 02 24	40	1st Flood	17.5	24	4.20	71
241	10.40	¼ way across	40 36 27	74 02 34	1	Slack	17.2	26	4.00	68
242	10.42	¼ way across	40 36 27	74 02 34	30	Flood	17.5	24	4.37	74
243	10.45	¼ way across	40 36 27	74 03 34	60	Flood	17.5	24	4.60	78
244	10.50	½ way across	40 36 25	74 02 48	1	Slack	17.2	24	4.12	70
245	10.52	½ way across	40 36 25	74 02 48	30	Flood	17.5	22	4.62	78
246	10.55	½ way across	40 36 25	74 02 48	60	Flood	17.5	22	4.74	80
247	11.00	¾ way across	40 36 23	74 02 03	1	Slack	17.2	24	4.18	71
248	11.02	¾ way across	40 36 23	74 02 03	30	Flood	17.8	22	4.90	84
249	11.05	¾ way across	40 36 23	74 02 03	60	Flood	17.8	22	4.88	84
250	11.10	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Slack	17.2	24	4.18	71
251	11.12	200 feet off Fort Wadsworth	40 36 21	74 03 12	30	Flood	17.8	22	4.87	84
252	11.15	200 feet off Fort Wadsworth	40 36 21	74 03 12	60	Flood	17.8	22	4.90	84
253	1.15	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Flood	17.8	24	5.02	87
254	1.17	200 feet off Fort Lafayette	40 36 29	74 02 24	20	Flood	17.8	22	5.30	91
255	1.20	200 feet off Fort Lafayette	40 36 29	74 02 24	40	Flood	17.8	22	5.30	91
256	1.25	¼ way across	40 36 27	74 02 34	1	Flood	17.8	24	5.00	87

TABLE CXX—Continued

16—CROSS SECTION OF THE NARROWS. OCTOBER 4, 1912—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
257	1.27	¼ way across	40 36 27	74 02 34	30	Flood	17.8	22	5.27	91
258	1.30	¼ way across	40 36 27	74 02 34	60	Flood	17.8	22	5.30	91
259	1.35	½ way across	40 36 25	74 02 48	1	Flood	17.8	24	5.12	88
260	1.37	½ way across	40 36 25	74 02 48	30	Flood	17.8	22	5.44	94
261	1.40	½ way across	40 36 25	74 02 48	60	Flood	17.8	22	5.44	94
262	1.45	¾ way across	40 36 23	74 03 02	1	Flood	17.8	24	5.08	88
263	1.47	¾ way across	40 36 23	74 03 02	30	Flood	17.8	22	5.38	93
264	1.50	¾ way across	40 36 23	74 03 02	60	Flood	17.8	22	5.40	93
265	1.55	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Flood	17.8	24	5.08	88
266	1.57	200 feet off Fort Wadsworth	40 36 21	74 03 12	30	Flood	17.8	22	5.37	93
267	2.00	200 feet off Fort Wadsworth	40 36 21	74 03 12	60	Flood	17.8	22	5.40	93

17—CROSS SECTION OF EAST RIVER BELOW BROOKLYN BRIDGE. NOVEMBER 26, 1912

High water occurred at Governors Island at 10.00 A. M. Low water at 4.10 P. M. The wind was northwest, with a velocity of 20 miles per hour.

	A. M.									
268	8.40	200 feet off Pier 10, New York	40 42 09	74 00 22	1	Flood	8.3	44	5.40	73
269	8.42	200 feet off Pier 10, New York	40 42 09	74 00 22	20	Flood	8.9	40	5.60	77
270	8.45	200 feet off Pier 10, New York	40 42 09	74 00 22	30	Flood	8.9	40	5.60	77
271	8.50	¼ way across	40 42 07	74 00 17	1	Flood	8.3	44	5.40	73
272	8.52	¼ way across	40 42 07	74 00 17	20	Flood	8.9	40	5.60	77
273	8.55	¼ way across	40 42 07	74 00 17	40	Flood	8.9	40	5.60	77
274	9.00	½ way across	40 42 03	74 00 11	1	Flood	8.3	44	5.50	75
275	9.02	½ way across	40 42 03	74 00 11	20	Flood	8.9	40	5.60	77
276	9.05	½ way across	40 42 03	74 00 11	40	Flood	8.9	40	5.60	77
277	9.10	¾ way across	40 42 00	74 00 05	1	Flood	8.3	42	5.20	71
278	9.12	¾ way across	40 42 00	74 00 05	20	Flood	8.9	38	5.50	76
279	9.15	¾ way across	40 42 00	74 00 05	35	Flood	8.9	38	5.50	76
280	9.20	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Flood	8.3	42	5.10	70
281	9.22	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	20	Flood	8.9	38	5.30	73
282	9.25	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	35	Flood	8.9	38	5.40	74
283	11.00	200 feet off Pier 10, New York	40 42 09	74 00 22	1	Beginning Ebb	8.3	40	5.10	70
284	11.02	200 feet off Pier 10, New York	40 42 09	74 00 22	20	Ebb	8.9	40	5.20	72
285	11.05	200 feet off Pier 10, New York	40 42 09	74 00 22	30	Ebb	8.9	40	5.20	72
286	11.10	¼ way across	40 42 07	74 00 17	1	Ebb	8.3	40	5.10	70
287	11.12	¼ way across	40 42 07	74 00 17	20	Ebb	8.9	40	5.20	72
288	11.15	¼ way across	40 42 07	74 00 17	40	Ebb	8.9	40	5.20	72
289	11.20	½ way across	40 42 03	74 00 11	1	Ebb	8.3	40	5.20	71
290	11.22	½ way across	40 42 03	74 00 11	20	Ebb	8.9	40	5.20	72
291	11.25	½ way across	40 42 03	74 00 11	40	Ebb	8.9	40	5.20	72
292	11.30	¾ way across	40 42 00	74 00 05	1	Ebb	8.3	40	5.00	68
293	11.32	¾ way across	40 42 00	74 00 05	20	Ebb	8.9	38	5.10	70
294	11.35	¾ way across	40 42 00	74 00 05	35	Ebb	8.9	38	5.10	70
295	11.40	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Ebb	8.3	40	5.00	68
296	11.42	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	20	Ebb	8.9	38	5.10	70
297	11.45	200 feet off Pier 10, Brooklyn	40 41 57	74 00 00	35	Ebb	8.9	38	5.10	70

TABLE CXX—Continued

17—CROSS SECTION OF EAST RIVER BELOW BROOKLYN BRIDGE. NOVEMBER 26, 1912—Continued.

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
298	2.25	200 feet off Pier 10, New York.......	40 42 09	74 00 22	1	Ebb	8.9	38	4.80	66
299	2.28	200 feet off Pier 10, New York.......	40 42 09	74 00 22	20	Ebb	8.9	38	5.00	70
300	2.30	200 feet off Pier 10, New York.......	40 42 09	74 00 22	30	Ebb	8.9	38	5.10	71
301	2.34	¼ way across.....................	40 42 07	74 00 17	1	Ebb	8.9	38	4.70	65
302	2.36	¼ way across.....................	40 42 07	74 00 17	20	Ebb	8.9	38	5.00	70
303	2.38	¼ way across.....................	40 42 07	74 00 17	40	Ebb	8.9	38	5.00	70
304	2.41	½ way across.....................	40 42 03	74 00 11	1	Ebb	8.9	38	4.80	66
305	2.43	½ way across.....................	40 42 03	74 00 11	20	Ebb	8.9	38	5.00	70
306	2.45	½ way across.....................	40 42 03	74 00 11	40	Ebb	8.9	38	5.00	70
307	2.48	¾ way across.....................	40 42 00	74 00 05	1	Ebb	8.9	38	4.80	66
308	2.50	¾ way across.....................	40 42 00	74 00 05	20	Ebb	8.9	38	5.00	70
309	2.52	¾ way across.....................	40 42 00	74 00 05	35	Ebb	8.9	38	5.00	70
310	2.55	200 feet off Pier 10, Brooklyn........	40 41 57	74 00 00	1	Ebb	8.9	38	4.90	68
311	2.57	200 feet off Pier 10, Brooklyn........	40 41 57	74 00 00	20	Ebb	8.9	38	5.00	70
312	3.00	200 feet off Pier 10, Brooklyn........	40 41 57	74 00 00	35	Ebb	8.9	38	5.00	70

TABLE CXXI

Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1912
Averages for various parts of the harbor

Data for this table are contained in Table CXX.

Location	Number of analyses	Averages: C. C. per litre	Averages: per cent. saturation	Samples included in the averages
Upper bay	24	5.37	75	7–8, 13–14, 23–24, 33–34, 43–44, 53–54, 65–66, 75–76, 85–86, 95–96, 105–106, 115–116.
Hudson river	75	3.74	60	3–4, 11–12, 21–22, 31–32, 41–42, 55–56, 59, 63–64, 77–78, 83–84, 97–98, 103–104, 117–118, 128–177.
East river	115	4.15	62	1–2, 9–10, 19–20, 29–30, 39–40, 57–58, 60–62, 79–82, 99–102, 119–120, 178–222, 268–312.
Harlem river	1	0.50	9	127.
Kill van Kull	22	5.22	74	15–16, 25–26, 35–36, 45–46, 51–52, 67–68, 73–74, 87–88, 93–94, 107–108, 113–114.
The Narrows	69	5.10	81	5–6, 17–18, 27–28, 37–38, 47–50, 69–72, 89–92, 109–112, 223–267.
Gowanus canal	3	0.60	12	122–124.
Buttermilk channel	3	0.60	12	121, 125–126.

TABLE CXXII

Average Volume and Percentage of Saturation of Dissolved Oxygen in the Water in the Year 1912
Averages of samples taken at Surface, Mid-depth and Bottom for various parts of the harbor

Data for this table are contained in Table CXX.

Location	Depths											
	Surface				Mid-depth				Bottom			
	No. of analyses	Averages: C. C. per litre	Averages: per cent. saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Upper bay	12	5.38	75	7, 13, 23, 33, 43, 53, 65, 75, 85, 95, 105, 115.	—	—	—	No mid-depth samples.	12	5.35	76	8, 14, 24, 34, 44, 54, 66, 76, 86, 96, 106, 116.
Hudson river	33	3.69	58	3, 11, 21, 31, 41, 55, 59, 63, 77, 83, 97, 103, 117, 128–132, 133, 136, 139, 142, 145, 148, 151, 154, 157, 160, 163, 166, 169, 172, 175.	15	3.17	58	134, 137, 140, 143, 146, 149, 152, 155, 158, 161, 164, 167, 170, 173, 176.	27	4.10	65	4, 12, 22, 32, 42, 56, 64, 78, 84, 98, 104, 118, 135, 138, 141, 144, 147, 150, 153, 156, 159, 162, 165, 168, 171, 174, 177.
East river	43	4.18	61	1, 9, 19, 29, 39, 57, 60–61, 79, 81, 99, 101, 119, 178, 181, 184, 187, 190, 193, 196, 199, 202, 205, 208, 211, 214, 217, 220, 268, 271, 274, 277, 280, 283, 286, 289, 292, 295, 298, 301, 304, 307, 310.	30	3.99	60	179, 182, 185, 188, 191, 194, 197, 200, 203, 206, 209, 212, 215, 218, 221, 269, 272, 275, 278, 281, 284, 287, 290, 293, 296, 299, 302, 305, 308, 311.	42	4.17	61	2, 10, 20, 30, 40, 58, 62, 80, 82, 100, 102, 120, 180, 183, 186, 189, 192, 195, 198, 201, 204, 207, 210, 213, 215, 219, 222, 270, 273, 276, 279, 282, 285, 288, 291, 294, 297, 300, 303, 306, 309, 312.
Harlem river	1	0.50	9	127 (taken in slip).	—	—	—	No mid-depth samples.	—	—	—	No deep samples.
Kill van Kull	11	5.25	74	15, 25, 35, 45, 51, 67, 73, 87, 93, 107, 113.	—	—	—	No mid-depth samples.	11	5.19	74	16, 26, 36, 46, 52, 68, 74, 88, 94, 108, 114.
The Narrows	27	5.07	79	5, 17, 27, 37, 47, 49, 69, 71, 89, 91, 109, 111, 223, 226, 229, 232, 235, 238, 241, 244, 247, 250, 253, 256, 259, 262, 265.	15	4.82	82	224, 227, 230, 233, 236, 239, 242, 245, 248, 251, 254, 257, 260, 263, 266.	27	5.28	83	6, 18, 28, 38, 48, 50, 70, 72, 90, 92, 110, 112, 225, 228, 231, 234, 237, 240, 243, 246, 249, 252, 255, 258, 261, 264, 267.
Gowanus canal	3	0.60	12	122–124.	—	—	—	No mid-depth samples.	—	—	—	No deep samples.
Buttermilk channel	3	0.60	12	121, 125–126 (taken in slip).	—	—	—	No mid-depth samples.	—	—	—	No deep samples.

TABLE CXXIII

Average Volume and Percentage of Saturation of Dissolved Oxygen in the Water in the Year 1912
Average, of samples taken on Ebb and Flood Currents for various parts of the harbor

Data for this table are contained in Table CXX.

Location	Currents							
	Ebb Currents				Flood Currents			
	No. of analyses	Averages: C. C. per litre	Averages: per cent. saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Upper Bay	13	5.35	73	7, 13–14, 33–34, 53–54, 65–66, 85–86, 105–106.	11	5.40	78	8, 23–24, 43–44, 75–76, 95–96, 115–116.
Hudson river	51	3.76	60	3–4, 11–12, 31–32, 41, 55–56, 59, 63–64, 83–84, 103–104, 117, 129–132, 148–177.	24	3.68	61	21–22, 42, 77–78, 97–98, 118, 128, 133–147.
East river	75	4.09	61	1–2, 9–10, 29–30, 57–58, 60–62, 81–82, 101–102, 193–222, 283–312.	40	4.27	63	19–20–39–40, 79–80, 99–100, 119–120, 178–192, 268–282.
Harlem river	—	—	—	No samples on ebb current.	1	0.50	9	127 (taken in slip).
Kill van Kull	12	5.33	74	15–16, 35–36, 51–52, 67–68, 87–88, 107–108.	10	5.09	75	25–26, 45–46, 73–74, 93–94, 113–114.
The Narrows	32	4.82	75	5, 17–18, 37, 49–50, 69–70, 89–90, 109–110, 223–238, 241, 244, 247, 250.	37	5.34	86	6, 27–28, 38, 47–48, 71–72, 91–92, 111–112, 239–240, 242–243, 245–246, 248–249, 251–267.
Gowanus canal	—	—	—	No samples on ebb current.	3	0.60	12	122–124.
Buttermilk channel	3	0.60	12	121, 125–126.	—	—	—	No samples on flood current.

TABLE CXXIV

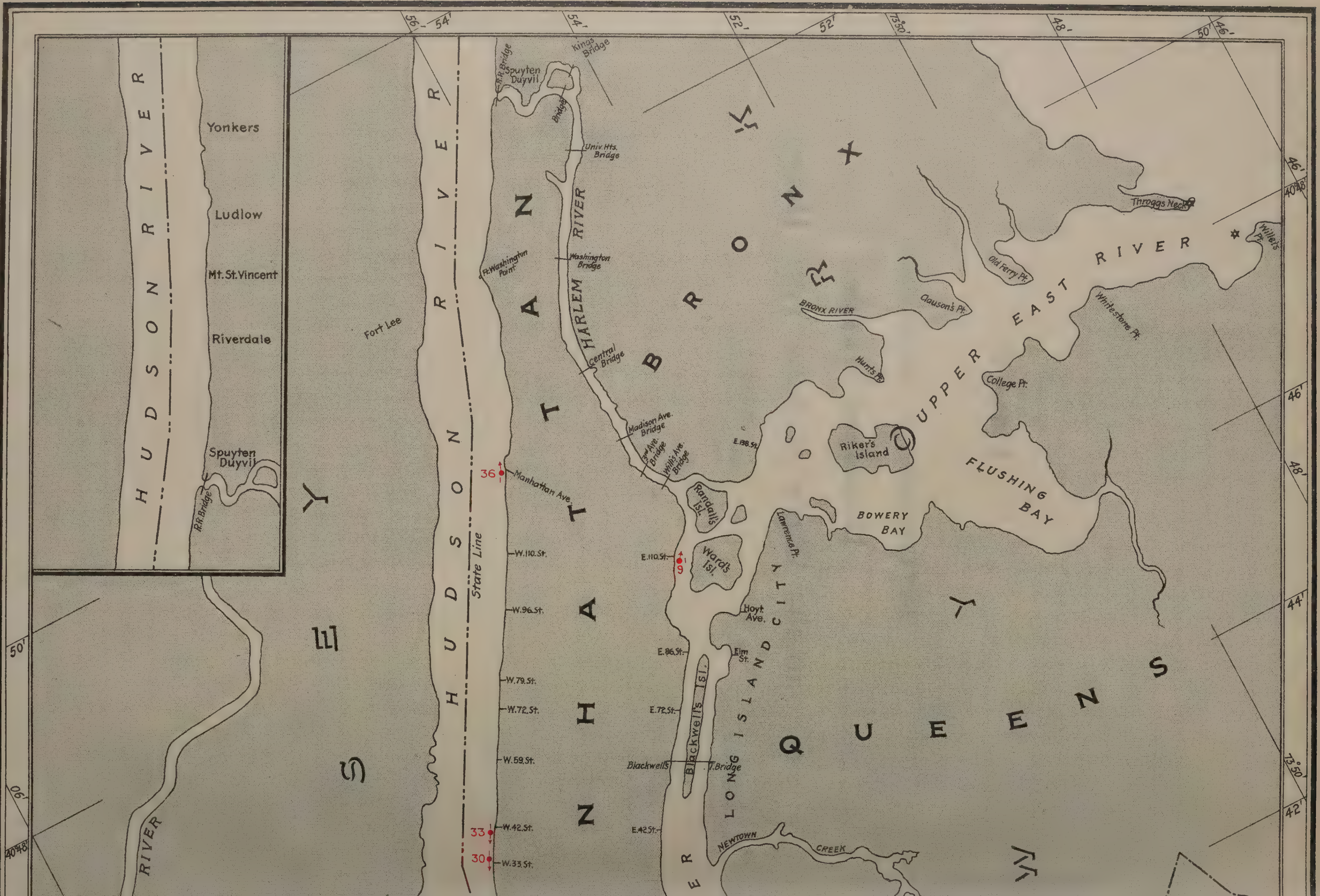
Average Volume and Percentage of Saturation of Dissolved Oxygen in the Water in the Year 1912
Summary of Tables CXXI, CXXII and CXXIII

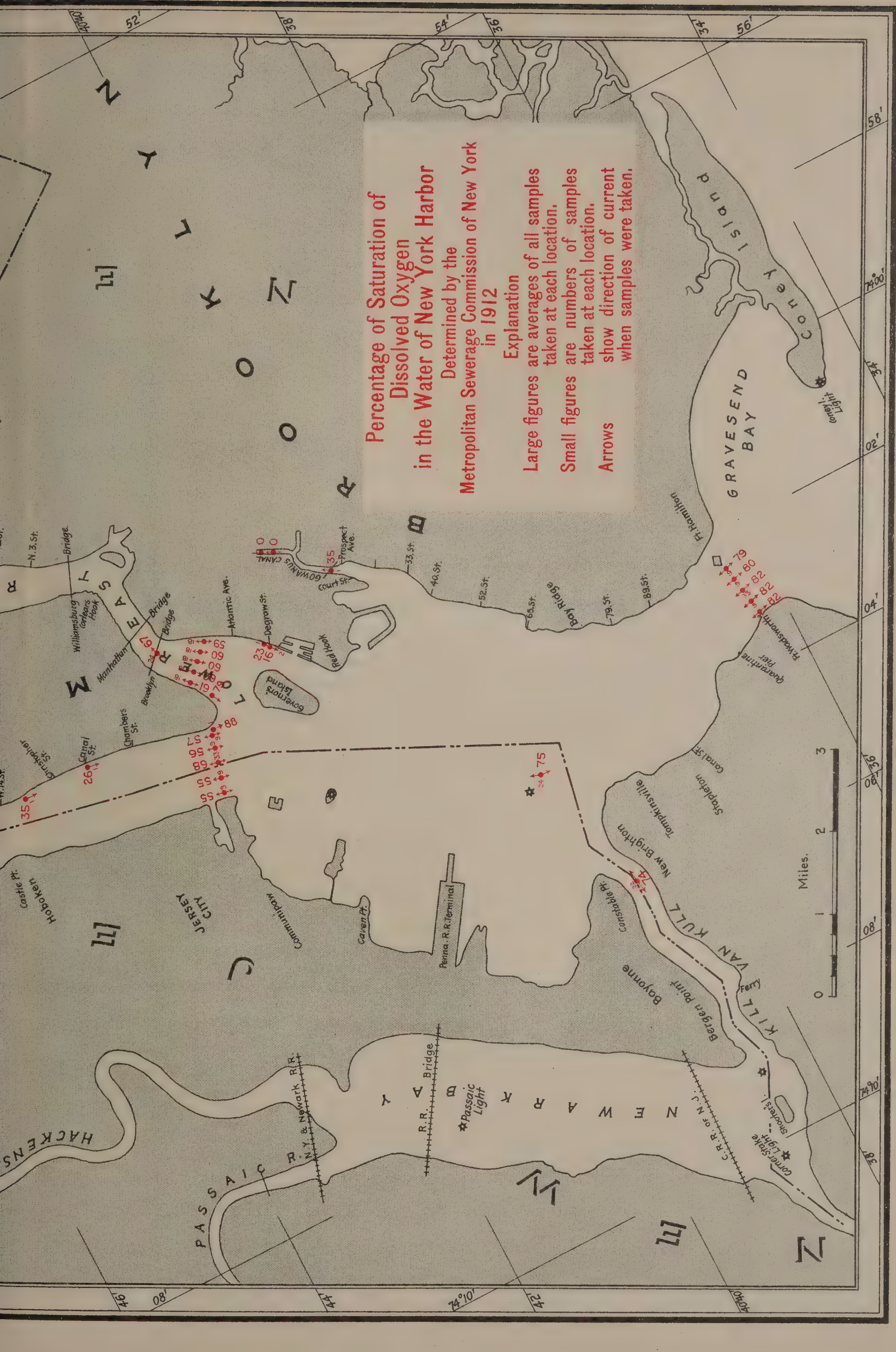
Data for this table are contained in Table CXX.

Location	All Depths and Tides			Depths									Currents					
				Surface			Mid-depth			Bottom			Ebb			Flood		
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation
Upper bay	24	5.37	75	12	5.38	75	—	—	—	12	5.35	76	13	5.35	73	11	5.40	78
Hudson river	75	3.74	60	33	3.69	58	15	3.17	58	27	4.10	65	51	3.76	60	24	3.68	61
East river	115	4.15	62	43	4.18	61	30	3.99	60	42	4.17	61	75	4.09	61	40	4.27	63
Harlem river	1	0.50	9	1	0.50	9	—	—	—	—	—	—	—	—	—	1	0.50	9
Kill van Kull	22	5.22	74	11	5.25	74	—	—	—	11	5.19	74	12	5.33	74	10	5.09	75
The Narrows	69	5.10	81	27	5.07	79	15	4.82	27	27	5.28	83	32	4.82	75	37	5.34	86
Gowanus canal	3	0.60	12	3	0.60	12	—	—	—	—	—	—	—	—	—	3	0.60	12
Buttermilk channel	3	0.60	12	3	0.60	12	—	—	—	—	—	—	3	0.60	12	—	—	—
	312	Total number of analyses, 1912, Nos. 1–312, inclusive. Samples A and B, taken in Passaic River, not included.																

Plate B

Percentage of Saturation of
Dissolved Oxygen
in the Water of New York Harbor
in 1912


HUDSON RIVER
Yonkers
Ludlow
Mt. St. Vincent
Riverdale
Spuyten Duyvil
R.R. Bridge
Fort Lee
NEW JERSEY
RIVER
HUDSON RIVER
State Line
Spuyten Duyvil
R.R. Bridge
Bridge
Kings Bridge
Univ. Hts. Bridge
Ft. Washington Point
Washington Bridge
HARLEM RIVER
Central Bridge
Madison Ave. Bridge
3rd Ave. Bridge
Willis Ave. Bridge
MANHATTAN
Manhattan Ave.
36
W. 110 St.
W. 96 St.
W. 79 St.
W. 72 St.
W. 59 St.
W. 42 St.
W. 33 St.
33
30
E. 110 St.
9
E. 86 St.
E. 72 St.
Blackwells
Blackwell's Isl.
Bridge
E. 42 St.
E. 138 St.
Randall's Isl.
Ward's Isl.
BRONX
BRONX RIVER
Old Ferry Pt.
Clauson's Pt.
Hunts Pt.
Throggs Neck
Willets Pt.
UPPER EAST RIVER
Whitestone Pt.
College Pt.
Riker's Island
FLUSHING BAY
BOWERY BAY
Lawrence Pt.
LONG ISLAND CITY
Hoyt Ave.
Elm St.
NEWTOWN CREEK
QUEENS
NEW YORK
ER
56'
54'
54'
52'
52'
73°50'
48'
50'
46'
46'
40°48'
46'
48'
44'
73°50'
42'
50'
06'
40°48'



Percentage of Saturation of Dissolved Oxygen in the Water of New York Harbor

Determined by the Metropolitan Sewerage Commission of New York in 1912

Explanation

Large figures are averages of all samples taken at each location.

Small figures are numbers of samples taken at each location.

Arrows show direction of current when samples were taken.

B

INTRODUCTION TO TABLES CXXV, CXXVI, CXXVII, CXXVIII, CXXIX

These tables, containing the results of analyses for dissolved oxygen made in the year 1913, follow the same plan as the similar tables for 1911 and 1912. In Table CXXV are contained the results of analyses made in various parts of the harbor in 1913. In Tables CXXVI, CXXVII and CXXVIII are shown the averages of results from observations at various locations, depths and tides, computed from the data contained in Table CXXV. In Table CXXIX is given a summary of the results of these calculations.

TABLE CXXV

VOLUME AND PERCENTAGE OF SATURATION OF DISSOLVED OXYGEN IN THE WATER IN THE YEAR 1913

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Section No.	Location	Date of Collection	Page
1	East river, Hudson river, Upper bay, Kill van Kull and Narrows	Jan. 9, 1913	673
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4	Slips of Lower East river and Gowanus canal	Feb. 17, 1913	674
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14	East river at Brooklyn Bridge	June 17, 1913	677
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16	Narrows, Cross-section between Forts Lafayette and Wadsworth	July 3, 1913	680
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20	Robbins Reef	July 10, 1913	685
21	Kill van Kull, Cross-section at Sailors Snug Harbor	July 11, 1913	686
22	East river, Throgs Neck, Cross-section to Cryders Point landing	July 14, 1913	687
23	Harlem river, Willis Avenue Bridge to Spuyten Duyvil	July 15, 1913	689
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26	East river, Cross-section at Pier 10	July 18, 1913	692
27	Narrows, Cross-section, Fort Lafayette to Fort Wadsworth	July 24, 1913	694
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30	East river at Pier 10	Aug. 15, 1913	696
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TABLE CXXV

1—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. JANUARY 9, 1913

High water occurred at Governors Island at 10.00 A. M. Low water at 4.00 P. M. The wind was northwest, with a velocity of 20 miles per hour.

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
313	7.45	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	2.8	64	6.00	68
314	7.47	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	3.3	64	6.00	70
315	8.00	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Flood	2.8	72	6.20	70
316	8.03	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Flood	3.3	72	6.00	70
317	8.23	Upper bay, at Robbins Reef bell buoy	40 39 15	74 03 50	1	Flood	2.8	60	6.30	72
318	8.25	Upper bay, at Robbins Reef bell buoy	40 39 15	74 03 50	40	Flood	3.3	60	6.40	74
319	8.40	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 07	1	Flood	2.8	60	6.10	70
320	8.43	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 07	30	Flood	3.3	60	6.20	71
321	9.06	The Narrows, midway between forts	40 36 25	74 02 48	1	Flood	3.9	52	6.80	82
322	9.09	The Narrows, midway between forts	40 36 25	74 02 48	60	Flood	3.9	52	6.80	82
323	11 20	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	3.3	64	5.60	65
324	11.23	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	3.3	64	5.60	65
325	11.40	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	3.3	72	5.70	65
326	11.43	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Ebb	3.3	72	5.70	65
327	P. M. 12.15	Upper bay, at Robbins Reef bell buoy	40 39 15	74 03 50	1	Ebb	3.3	66	6.00	70
328	12.18	Upper bay, at Robbins Reef bell buoy	40 39 15	74 03 50	40	Ebb	3.3	56	6.00	70
329	12.40	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 07	1	Ebb	3.3	64	6.00	70
330	12.45	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 07	30	Ebb	3.3	64	6.00	70
331	1.30	The Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	3.3	56	6.10	71
332	1.35	The Narrows, midway between forts	40 36 25	74 02 48	60	Ebb	3.3	56	6.10	71

2—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND THE NARROWS. FEBRUARY 18, 1913

High water occurred at Governors Island at 6.15 P. M. Low water at 12.50 P. M. The wind was northwest, with a velocity of 30 miles per hour.

Sample No.	Hour	Approximate location	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	C. C. per litre	Per cent. saturation
333	A. M. 10.00	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	1.7	30	5.40	62
334	10.05	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	1.7	30	5.40	62
335	10.30	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	1.7	36	5.80	66
336	10.35	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Ebb	1.7	36	5.80	66
337	11.10	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Ebb	1.7	30	5.90	68
338	11.15	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Ebb	1.7	30	6.00	69
339	11.30	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 07	1	Ebb	1.7	40	5.80	65
340	11.35	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 07	30	Ebb	1.7	40	5.80	65
341	12.00	The Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	1.7	30	6.00	69
342	P. M. 12.05	The Narrows, midway between forts	40 36 25	74 02 48	60	Ebb	1.7	28	6.10	70
343	3.25	The Narrows, midway between forts	40 36 25	74 02 48	1	Flood	1.7	28	6.60	76
344	3.30	The Narrows, midway between forts	40 36 25	74 02 48	60	Flood	1.7	24	6.70	78
345	4.00	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 07	1	Flood	1.7	32	6.20	71
346	4.05	Kill van Kull, off Sailors Snug Harbor	40 38 50	74 06 07	30	Flood	1.7	30	6.30	72
347	4.20	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	1	Flood	1.7	30	6.20	71

TABLE CXXV—Continued

2—EAST RIVER, HUDSON RIVER, UPPER BAY, KILL VAN KULL AND NARROWS. FEBRUARY 18, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
348	4.25	Upper bay, near Robbins Reef bell buoy	40 39 10	74 03 50	40	Flood	1.7	30	6.20	71
349	4.50	Hudson river, midstream off Pier A	40 42 19	74 01 34	1	Flood	1.7	40	5.80	65
350	4.55	Hudson river, midstream off Pier A	40 42 19	74 01 34	30	Flood	1.7	36	5.90	67
351	5.10	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	1.7	32	5.60	64
352	5.15	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	1.7	32	5.70	65

3—SLIPS, EAST 109TH STREET AND WEST 129TH STREET, MANHATTAN. FEBRUARY 14, 1913.

High water occurred at Governors Island at 1.45 P. M. The wind was northwest, light.

	P. M.									
353	12.00	Slip at foot of East 109th street, Harlem river	40 47 24	73 56 11	1	Flood	3.9	32	5.40	68
354	2.00	Slip at foot of West 129th street, Hudson river	40 48 07	73 57 45	1	Flood	2.2	62	6.00	66

4—SLIPS OF LOWER EAST RIVER AND GOWANUS CANAL. FEBRUARY 17, 1913.

High water occurred at Governors Island at 5.20 P. M. Low water at 11.50 A. M. The wind was northwest, light.

	A. M.									
355	10.30	Slip at foot of De Graw street, East river, Broooklyn	40 41 13	74 00 25	1	Ebb	4.4	30	5.20	67
356	11.00	Gowanus canal, at Hamilton avenue bridge	40 40 17	73 59 56	1	Ebb	3.9	28	5.20	65
357	12.00	Gowanus canal, at DeGraw street, one block below pumping station at head of canal	40 41 13	74 00 25	1	Slack	7.2	30	4.40	60

5—SLIPS OF LOWER EAST RIVER. FEBRUARY 17, 1913.

High water occurred at Governors Island at 5.20 P. M. Low water at 11.50 A. M. The wind was northwest, light.

	P. M.									
358	4.00	Slip of East river just west of Pier 4, Manhattan	40 42 04	74 00 43	1	Flood	3.9	30	5.40	68
359	4.15	Slip of East river at foot of Coenties slip	40 42 08	74 00 35	1	Flood	3.9	30	5.10	64

6—SLIPS OF EAST RIVER BELOW 24TH STREET. FEBRUARY 20, 1913

High water occurred at Governors Island at 7.35 A. M. Low water at 2.15 P. M. The wind was northwest, light.

	A. M.									
360	10.00	Peck slip, Bridgeport Line pier, East river	40 42 26	74 00 04	1	Ebb	3.9	30	5.20	65
361	10.20	Slip south of dumping pier near Brooklyn Bridge	40 42 28	74 00 01	1	Ebb	3.9	30	5.20	65
362	11.00	Slip south of Pier 32, East river	40 42 42	73 59 53	1	Ebb	3.9	30	5.10	64
363	11.20	Slip north of Pier 32, East river, Norwich Line pier	40 42 42	73 59 50	1	Ebb	3.9	30	5.10	64
	P. M.									
364	12.30	Slip between foot of East 23d and East 24th streets, East river	40 44 08	73 58 31	1	Ebb	4.4	32	5.00	64
365	1.00	Slip north of recreation pier at foot of East 24th street	40 44 12	73 58 21	1	Ebb	3.9	32	5.20	65

TABLE CXXV—Continued

7—SLIPS OF HUDSON RIVER. FEBRUARY 20, 1913

High water occurred at Governors Island at 7.35 A. M. Low water at 2.15 P. M. The wind was northwest, light.

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
366	1.30	Slip at foot of North Moore street, Manhattan, Hudson river	40 43 13	74 00 48	1	Ebb	4.4	32	5.00	64
367	1.45	Slip at foot of Canal street, Pier 32, North river	40 43 28	74 00 45	1	Ebb	4.4	32	5.00	64
368	2.00	Slip at foot of Canal street, north of dumping pier	40 43 32	74 00 43	1	Ebb	4.4	32	5.10	65
369	2.15	Slip between foot Jay and Duane streets, Manhattan, Hudson river	40 43 06	74 00 50	1	Ebb	4.4	32	5.10	65
370	2.30	Slip between foot Vesey and Fulton streets, Manhattan, Hudson river	40 42 49	74 00 53	1	Ebb	4.4	32	5.20	67
371	3.00	Slip foot of Desbrosses street, Hudson River Day Line	40 43 27	74 00 48	1	Ebb	4.4	32	4.80	62

8—WALLABOUT CANAL. FEBRUARY 21, 1913

High water occurred at Governors Island at 7.55 A. M. Low water at 3.15 P. M. The wind was northwest, light.

	A. M.									
372	11.30	Wallabout canal, at head of canal by Fleeman avenue market	40 42 00	73 58 08	1	Ebb	5.6	32	4.65	61
373	11.50	Wallabout canal, at head of canal by dumping pier on Navy Yard side	40 42 00	73 58 13	1	Ebb	5.6	32	4.70	61

9—NEWTOWN CREEK. FEBRUARY 21, 1913

High water occurred at Governors Island at 7.55 A. M. Low water at 3.15 P. M. The wind was northwest, light.

	P. M.									
374	12.30	Newtown creek, at Grand Street Bridge (Metropolitan avenue)	40 42 52	73 55 54	1	Ebb	5.6	38	1.60	21
375	1.15	Newtown creek, at Vernon Avenue Bridge	40 44 22	73 57 20	1	Ebb	5.6	36	1.40	18
376	2.30	Newtown creek, at Grand Street Bridge (Metropolitan avenue)	40 42 52	73 57 20	1	Ebb	5.6	38	1.20	15

10—SLIPS IN LOWER EAST RIVER. FEBRUARY 25, 1913

High water occurred at Governors Island at 12.10 A. M. Low water at 6.30 P. M. The wind was northwest, light.

	P. M.									
377	4.15	Slip west of Pier 4, East river, Manhattan	40 42 04	74 00 43	1	Ebb	3.3	36	5.10	62
378	4.30	Slip at foot of Coenties slip, East river, Manhattan	40 42 08	74 00 35	1	Ebb	3.3	36	5.00	61

11—HUDSON RIVER. APRIL 5, 1913

High water occurred at Governors Island at 7.45 A. M. Low water at 2.25 P. M. The wind was northwest, with a velocity of 30 miles per hour.

	A. M.									
379	10.35	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	7.8	84	6.00	74
380	10.38	Hudson river, midstream, off Pier A	40 42 19	74 01 34	20	Ebb	7.8	80	5.90	73
381	10.42	Hudson river, midstream, off Pier A	40 42 19	74 01 34	40	Ebb	7.8	70	5.80	73

TABLE CXXV—Continued

11—HUDSON RIVER. APRIL 5, 1913—Continued

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
382	11.10	Hudson river, midstream, off Stevens Point	40 44 40	74 01 04	1	Ebb	7.8	86	6.20	76
383	11.13	Hudson river, midstream, off Stevens Point	40 44 40	74 01 04	20	Ebb	7.8	82	6.10	75
384	11.16	Hudson river, midstream, off Stevens Point	40 44 40	74 01 04	40	Ebb	7.8	76	5.90	74

12—NARROWS, KILL VAN KULL, ROBBINS REEF, HUDSON AND EAST RIVERS. MAY 29, 1913

High water occurred at Governors Island at 4.10 P. M. Low water at 10.20 A. M. The wind was northwest, with a velocity of 40 miles per hour.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	C. C. per litre	Per cent. saturation
385	A. M. 10.05	Narrows, midstream, between forts	40 36 25	74 02 48	1	Flood	15.6	44	4.40	68
386	10.20	Narrows, midstream, between forts	40 36 25	74 02 48	30	Flood	14.4	30	5.20	84
387	10.30	Narrows, midstream, between forts	40 36 25	74 02 48	60	Flood	14.4	36	5.60	91
388	11.40	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	15.6	44	3.90	61
389	11.50	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	15	Flood	15.0	40	4.40	70
390	M 12.00	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	30	Flood	15.0	42	4.90	77
391	P. M. 12.22	Robbins Reef, near bell buoy	40 39 15	74 03 50	1	Flood	15.0	38	4.60	73
392	12.55	Robbins Reef, near bell buoy	40 39 15	74 03 50	20	Flood	14.4	36	3.90	60
393	1.05	Robbins Reef, near bell buoy	40 39 15	74 03 50	40	Flood	14.4	34	6.00	95
394	2.00	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Flood	15.3	62	4.60	70
395	2.15	Hudson river, midstream, off Pier A	40 42 19	74 01 34	15	Flood	15.0	58	4.70	71
396	2.30	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Flood	14.7	44	4.30	64
397	3.05	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	15.3	52	4.70	72
398	3.15	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	15	Flood	15.0	48	4.50	70
399	3.30	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	15.0	56	2.90	45
400	4.45	Narrows, midstream, between forts	40 36 25	74 02 48	1	Ebb	15.0	34	5.20	84
401	5.00	Narrows, midstream, between forts	40 36 25	74 02 48	30	Ebb	14.7	32	5.90	93
402	5.10	Narrows, midstream, between forts	40 36 25	74 02 48	60	Ebb	14.4	26	5.90	94
403	5.55	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	15.0	40	5.10	86
404	6.05	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	15	Ebb	15.0	20	5.10	81
405	6.15	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	30	Ebb	15.0	40	5.70	90
406	6.45	Robbins Reef, near bell buoy	40 39 15	74 03 50	1	Ebb	15.0	42	5.00	78
407	7.00	Robbins Reef, near bell buoy	40 39 15	74 03 50	20	Ebb	14.4	40	5.50	84
408	7.15	Robbins Reef, near bell buoy	40 39 15	74 03 50	40	Ebb	14.4	34	5.10	78
409	7.50	Hudson river, midstream, opposite Colgates	40 42 19	74 01 34	1	Ebb	14.4	60	5.00	75
410	8.00	Hudson river, midstream, opposite Colgates	40 42 19	74 01 34	15	Ebb	14.4	52	5.30	79
411	8.10	Hudson river, midstream, opposite Colgates	40 42 19	74 01 34	30	Ebb	14.4	46	5.50	84

TABLE CXXV—Continued

13—EAST RIVER, HUDSON RIVER, ROBBINS REEF, KILL VAN KULL AND NARROWS. JUNE 11, 1913

High water occurred at Governors Island at 2.10 P. M. Low water at 8.10 A. M. The wind was west, with a velocity of 5 miles per hour.

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
412	9.05	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	16.5	34	2.49	40
413	9.15	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	15	Flood	16.5	34	2.80	45
414	9.25	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	16.5	34	2.51	41
415	9.45	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Flood	17.7	51	3.77	60
416	9.50	Hudson river, midstream, off Pier A	40 42 19	74 01 34	15	Flood	17.7	47	5.08	82
417	9.55	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Flood	17.5	40	3.97	65
418	10.30	Robbins Reef, near bell buoy	40 39 10	74 03 50	1	Flood	17.7	43	4.37	71
419	10.40	Robbins Reef, near bell buoy	40 39 10	74 03 50	20	Flood	17.7	38	5.90	97
420	10.50	Robbins Reef, near bell buoy	40 39 10	74 03 50	40	Flood	18.5	34	5.58	93
421	11.05	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	17.7	34	4.39	73
422	11.15	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	15	Flood	17.7	34	4.21	71
423	11.20	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	30	Flood	18.5	34	3.92	66
	P. M.									
424	12.05	Narrows, midstream, between forts	40 36 25	74 02 48	1	Flood	18.5	30	4.11	70
425	12.10	Narrows, midstream, between forts	40 36 25	74 02 48	30	Flood	17.7	30	4.21	70
426	12.15	Narrows, midstream, between forts	40 36 25	74 02 48	60	Flood	16.8	33	4.15	67
427	1.05	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	18.4	40	4.83	85
428	1.15	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	15	Flood	17.8	40	4.56	75
429	1.25	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	17.8	39	5.08	84
430	1.50	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Flood	18.4	40	4.11	68
431	1.55	Hudson river, midstream, off Pier A	40 42 19	74 01 34	15	Flood	17.8	43	4.12	69
432	2.00	Hudson river, midstream, off Pier A	40 42 19	74 01 34	30	Flood	17.2	40	4.72	77
433	2.45	Robbins Reef, near bell buoy	40 39 10	74 03 50	1	Ebb	17.8	29	5.26	89
434	2.50	Robbins Reef, near bell buoy	40 39 10	74 03 50	20	Ebb	17.8	24	5.36	91
435	3.00	Robbins Reef, near bell buoy	40 39 10	74 03 50	40	Ebb	17.2	27	5.83	98
436	3.30	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	18.4	36	4.61	78
437	3.35	Kill van Kull, midstream, off Sailors Harbor	40 38 50	74 06 25	15	Ebb	17.8	35	4.40	73
438	3.45	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	30	Ebb	17.2	50	4.33	72
439	4.20	Narrows, midstream, between forts	40 36 25	74 02 48	1	Ebb	18.0	29	5.66	96
440	4.25	Narrows, midstream, between forts	40 36 25	74 02 48	30	Ebb	17.2	28	5.32	89
441	4.35	Narrows, midstream, between forts	40 36 25	74 02 48	60	Ebb	16.7	24	6.07	102

14—EAST RIVER AT BROOKLYN BRIDGE. JUNE 17, 1913

Low water occurred at Governors Island at 1.45 P. M. The wind was southwest, with a velocity of 5 miles per hour.

	P. M.									
442	2.13	100 feet off North Pier headline	40 42 25	73 59 53	1	Flood	20.0	31	0.40	7
443	2.20	100 feet off North Pier headline	40 42 25	73 59 53	18	Flood	19.4	31	2.71	48
444	2.25	100 feet off North Pier headline	40 42 25	73 59 53	35	Flood	19.4	31	2.67	47
445	2.30	Midstream	40 42 20	73 59 48	1	Flood	19.4	31	2.73	48
446	2.35	Midstream	40 42 20	73 59 48	18	Flood	19.4	31	2.12	37

TABLE CXXV—Continued

14—EAST RIVER, HUDSON RIVER, ROBBINS REEF, KILL VAN KULL AND NARROWS. JUNE 11, 1913—Continued

Sample No.	Hour P. M.	Location of Samples: Approximate	Location of Samples: Latitude	Location of Samples: Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen: C. C. per litre	Oxygen: Per cent. saturation
			° ′ ″	° ′ ″						
447	2.40	Midstream	40 42 20	73 59 48	35	Flood	19.4	30	3.56	62
448	2.50	500 feet east of Brooklyn Bridge and 100 feet off pier headline on south shore	40 42 15	73 59 43	1	Flood	19.4	31	2.47	43
449	2.55	500 feet east of Brooklyn Bridge and 100 feet off pier headline on south shore	40 42 15	73 59 43	18	Flood	18.9	32	2.07	35
450	3.00	500 feet east of Brooklyn Bridge and 100 feet off pier headline on south shore	40 42 15	73 59 43	35	Flood	19.4	31	2.06	30

15—EAST RIVER, CROSS-SECTION, PIER NO. 10. JULY 2, 1913

High water occurred at Governors Island at 7.15 A. M. Low water at 1.10 P. M. The wind was southwest, with a velocity of 5 miles per hour.

Sample No.	Hour	Location of Samples: Approximate	Location of Samples: Latitude	Location of Samples: Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen: C. C. per litre	Oxygen: Per cent. saturation
	A. M.									
451	7.25	100 feet of west shore	40 42 09	74 00 22	1	Ebb	22.2	31	2.34	42
452	7.30	100 feet off west shore	40 42 09	74 00 22	15	Ebb	21.7	30	2.82	51
453	7.35	100 feet off west shore	40 42 09	74 00 22	30	Ebb	21.7	30	2.63	47
454	7.37	¼ way over	40 42 07	74 00 17	1	Ebb	21.7	30	2.49	43
455	7.41	¼ way over	40 42 07	74 00 17	15	Ebb	21.7	30	2.97	54
456	7.45	¼ way over	40 42 07	74 00 17	30	Ebb	21.7	26	2.94	54
457	7.50	½ way over	40 42 03	74 00 11	1	Ebb	21.4	26	2.30	42
458	7.52	½ way over	40 42 03	74 00 11	15	Ebb	21.7	26	2.56	47
459	7.55	½ way over	40 42 03	74 00 11	30	Ebb	21.7	30	3.32	60
460	8.00	¾ way over	40 42 00	74 00 05	1	Ebb	21.4	31	2.51	45
461	8.05	¾ way over	40 42 00	74 00 05	15	Ebb	21.4	26	2.63	48
462	8.10	¾ way over	40 42 00	74 00 05	30	Ebb	21.7	30	2.99	54
463	8.20	100 feet off east shore	40 41 57	74 00 00	1	Ebb	21.9	31	2.36	43
464	8.25	100 feet off east shore	40 41 57	74 00 00	15	Ebb	21.7	31	1.96	35
465	8.30	100 feet off east shore	40 41 57	74 00 00	30	Ebb	21.4	30	2.73	49
466	9.55	100 feet off west shore	40 42 09	74 00 22	1	Ebb	23.3	30	2.44	45
467	10.00	100 feet off west shore	40 42 09	74 00 22	15	Ebb	22.2	31	1.92	35
468	10.05	100 feet off west shore	40 42 09	74 00 22	30	Ebb	21.7	31	2.14	38
469	10.10	¼ way over	40 42 07	74 00 17	1	Ebb	22.2	31	2.28	41
470	10.12	¼ way over	40 42 07	74 00 17	15	Ebb	21.7	31	1.85	33
471	10.15	¼ way over	40 42 07	74 00 17	30	Ebb	21.7	31	3.04	55
472	10.20	½ way over	40 42 03	74 00 11	1	Ebb	22.0	31	1.90	33
473	10.25	½ way over	40 42 03	74 00 11	15	Ebb	22.0	35	1.54	26
474	10.27	½ way over	40 42 03	74 00 11	30	Ebb	21.7	36	2.67	48
475	10.28	¾ way over	40 42 00	74 00 05	1	Ebb	21.7	34	2.29	41
476	10.30	¾ way over	40 42 00	74 00 05	15	Ebb	21.7	31	1.52	25
477	10.35	¾ way over	40 42 00	74 00 05	30	Ebb	21.7	31	2.60	47
478	10.40	100 feet off east shore	40 41 57	74 00 00	1	Ebb	21.7	34	2.34	42
479	10.43	100 feet off east shore	40 41 57	74 00 00	15	Ebb	21.7	34	0.83	15
480	10.48	100 feet off east shore	40 41 57	74 00 00	30	Ebb	21.7	34	2.60	46
	P. M.									
481	12.30	100 feet off west shore	40 42 09	74 00 22	1	Flood	23.3	32	1.39	26
482	12.35	100 feet off west shore	40 42 09	74 00 22	15	Flood	22.2	31	1.42	26
483	12.40	100 feet off west shore	40 42 09	74 00 22	30	Flood	22.2	31	0.99	18
484	12.42	¼ way over	40 42 07	74 00 17	1	Flood	21.7	31	1.67	32
485	12.46	¼ way over	40 42 07	74 00 17	15	Flood	21.7	31	1.33	22
486	12.50	¼ way over	40 42 07	74 00 17	30	Flood	21.7	31	2.80	40
487	12.55	½ way over	40 42 03	74 00 11	1	Flood	21.7	31	0.69	13

TABLE CXXV—Continued

15—EAST RIVER, CROSS-SECTION, PIER NO. 10. JULY 2, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
488	12.57	½ way over	40 42 03	74 00 11	15	Flood	21.7	31	0.89	16
489	1.00	½ way over	40 42 03	74 00 11	30	Flood	21.7	31	1.85	34
490	1.07	¾ way over	40 42 00	74 00 05	1	Flood	21.7	31	1.89	34
491	1.10	¾ way over	40 42 00	74 00 05	15	Flood	21.7	31	2.22	40
492	1.12	¾ way over	40 42 00	74 00 05	30	Flood	21.7	31	0.90	16
493	1.17	100 feet off east shore	40 41 57	74 00 00	1	Flood	22.2	31	2.19	40
494	1.20	100 feet off east shore	40 41 57	74 00 00	15	Flood	21.7	34	1.85	33
495	1.25	100 feet off east shore	40 41 57	74 00 00	30	Flood	21.7	31	0.97	18
496	2.40	100 feet off west shore	40 42 09	74 00 22	1	Flood	22.8	26	1.75	32
497	2.43	100 feet off west shore	40 42 09	74 00 22	15	Flood	21.7	31	2.42	44
498	2.47	100 feet off west shore	40 42 09	74 00 22	30	Flood	21.7	30	2.41	53
499	2.50	¼ way over	40 42 07	74 00 17	1	Flood	22.2	33	3.67	67
500	2.53	¼ way over	40 42 07	74 00 17	15	Flood	22.2	33	1.85	33
501	2.55	¼ way over	40 42 07	74 00 17	30	Flood	21.7	31	2.11	38
502	3.00	½ way over	40 42 03	74 00 11	1	Flood	22.0	33	1.89	34
503	3.03	½ way over	40 42 03	74 00 11	15	Flood	22.0	33	1.45	26
504	3.06	½ way over	40 42 03	74 00 11	30	Flood	22.0	33	2.84	51
505	3.10	¾ way over	40 42 00	74 00 05	1	Flood	22.2	35	2.61	47
506	3.13	¾ way over	40 42 00	74 00 05	15	Flood	21.7	35	2.02	36
507	3.15	¾ way over	40 42 00	74 00 05	30	Flood	21.7	33	2.20	40
508	3.20	100 feet off east shore	40 41 57	74 00 00	1	Flood	22.2	33	2.59	45
509	3.23	100 feet off east shore	40 41 57	74 00 00	15	Flood	21.7	33	1.45	26
510	3.28	100 feet off east shore	40 41 57	74 00 00	30	Flood	21.7	33	1.97	36
511	4.55	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	1	Flood	22.2	33	1.54	28
512	4.58	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	15	Flood	21.7	36	0.85	15
513	5.03	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	30	Flood	21.7	33	2.31	41
514	5.06	½ way across	40 42 03	74 00 11	1	Flood	22.2	33	0.88	14
515	5.09	½ way across	40 42 03	74 00 11	15	Flood	21.7	33	1.58	29
516	5.12	½ way across	40 42 03	74 00 11	30	Flood	22.2	35	2.99	54
517	5.15	¾ way across	40 42 00	74 00 05	1	Flood	22.0	40	2.67	47
518	5.18	¾ way across	40 42 00	74 00 05	15	Flood	21.7	36	2.45	43
519	5.21	¾ way across	40 42 00	74 00 05	30	Flood	21.7	33	3.43	63
520	5.25	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Flood	21.7	31	2.29	41
521	5.28	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	15	Flood	21.7	36	2.35	42
522	5.31	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	30	Flood	21.7	36	2.54	44
523	6.20	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	1	Flood	22.2	34	0.84	15
524	6.22	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	15	Flood	21.7	33	2.63	47
525	6.25	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	30	Flood	21.7	33	2.32	42
526	6.30	¼ way across	40 42 07	74 00 17	1	Flood	21.7	32	1.58	29
527	6.35	¼ way across	40 42 07	74 00 17	15	Flood	21.1	32	2.36	40
528	6.38	¼ way across	40 42 07	74 00 17	30	Flood	21.7	34	3.13	55
529	6.41	½ way across	40 42 03	74 00 11	1	Ebb	21.7	33	1.81	32
530	6.45	½ way across	40 42 03	74 00 11	15	Ebb	21.7	32	3.15	57
531	6.48	½ way across	40 42 03	74 00 11	35	Ebb	21.7	32	2.81	50
532	6.52	¾ way across	40 42 00	74 00 05	1	Ebb	21.7	32	2.90	52
533	6.55	¾ way across	40 42 00	74 00 05	15	Ebb	21.7	32	2.13	38
534	7.00	¾ way across	40 42 00	74 00 05	30	Ebb	21.7	32	2.74	50
535	7.04	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Ebb	21.7	32	2.74	50
536	7.08	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	15	Ebb	21.7	32	2.05	37
537	7.10	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	30	Ebb	21.7	32	2.73	50

TABLE CXXV—Continued

16—NARROWS, CROSS SECTION, BETWEEN FORTS LAFAYETTE AND WADSWORTH. JULY 3, 1913

High water occurred at Governors Island at 8.05 A. M. Low water at 2.15 P. M. The wind was southwest, with a velocity of 5 miles per hour.

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
538	7.40	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Ebb	20.6	24	4.35	78
539	7.45	200 feet off Fort Lafayette	40 36 29	74 02 24	15	Ebb	20.8	20	3.60	65
540	7.50	200 feet off Fort Lafayette	40 36 29	74 02 24	30	Ebb	20.6	20	4.35	79
541	7.55	¼ way across	40 36 27	74 02 34	1	Ebb	20.8	22	3.44	62
542	8.00	¼ way across	40 36 27	74 02 34	20	Ebb	20.3	20	3.12	56
543	8.05	¼ way across	40 36 27	74 02 34	40	Ebb	20.0	21	2.48	62
544	8.15	½ way across	40 36 25	74 02 48	1	Ebb	20.6	24	3.35	60
545	8.17	½ way across	40 36 25	74 02 48	30	Ebb	20.6	24	3.89	69
546	8.20	½ way across	40 36 25	74 02 48	60	Ebb	20.0	21	4.30	79
547	8.25	¾ way across	40 36 23	74 03 02	1	Ebb	20.6	24	4.05	73
548	8.29	¾ way across	40 36 23	74 03 02	20	Ebb	20.6	20	3.66	66
549	8.32	¾ way across	40 36 23	74 03 02	40	Ebb	20.0	21	3.92	70
550	8.39	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Ebb	21.1	26	4.26	77
551	8.43	200 feet off Fort Wadsworth	40 36 21	74 03 12	20	Ebb	20.6	22	3.87	70
552	8.45	200 feet off Fort Wadsworth	40 36 21	74 03 12	40	Ebb	20.0	22	4.80	85
553	9.52	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Ebb	21.7	27	3.40	62
554	9.55	200 feet off Fort Lafayette	40 36 29	74 02 24	15	Ebb	21.7	23	3.71	70
555	10.00	200 feet off Fort Lafayette	40 36 29	74 02 24	30	Ebb	21.7	22	3.70	68
556	10.05	¼ way across	40 36 27	74 02 34	1	Ebb	21.7	26	3.19	59
557	10.10	¼ way across	40 36 27	74 02 34	20	Ebb	21.1	25	3.29	59
558	10.15	¼ way across	40 36 27	74 02 34	40	Ebb	20.6	20	4.48	81
559	10.20	½ way across	40 36 25	74 02 48	1	Ebb	21.7	32	3.30	60
560	10.25	½ way across	40 36 25	74 02 48	30	Ebb	21.1	22	3.81	69
561	10.30	½ way across	40 36 25	74 02 48	60	Ebb	20.6	20	4.40	90
562	10.33	¾ way across	40 36 23	74 03 02	1	Ebb	22.2	30	3.72	68
563	10.36	¾ way across	40 36 23	74 03 02	20	Ebb	20.6	20	4.04	73
564	10.40	¾ way across	40 36 23	74 03 02	40	Ebb	20.3	20	3.90	71
565	10.47	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Ebb	22.2	29	3.45	62
566	10.50	200 feet off Fort Wadsworth	40 36 21	74 03 12	20	Ebb	21.7	29	3.45	63
567	10.55	200 feet off Fort Wadsworth	40 36 21	74 03 12	40	Ebb	20.6	22	4.19	76
	P. M.									
568	12.10	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Ebb	22.0	29	4.74	86
569	12.15	200 feet off Fort Lafayette	40 36 29	74 02 24	15	Ebb	21.7	23	3.11	70
570	12.20	200 feet off Fort Lafayette	40 36 29	74 02 24	30	Ebb	21.2	23	3.74	68
571	12.25	¼ way across	40 36 27	74 02 34	1	Ebb	21.7	29	2.89	52
572	12.30	¼ way across	40 36 27	74 02 34	20	Ebb	21.7	27	2.78	50
573	12.35	¼ way across	40 36 27	74 02 34	40	Ebb	21.7	26	3.50	64
574	12.40	½ way across	40 36 25	74 02 48	1	Ebb	21.7	27	2.85	52
575	12.43	½ way across	40 36 25	74 02 48	30	Ebb	21.7	27	2.62	48
576	12.45	½ way across	40 36 24	74 02 48	60	Ebb	21.7	25	3.73	68
577	12.50	¾ way across	40 36 23	74 03 02	1	Ebb	21.7	29	3.51	64
578	12.55	¾ way across	40 36 23	74 02 03	20	Ebb	21.7	27	3.43	63
579	1.00	¾ way across	40 36 23	74 03 02	40	Ebb	21.7	27	3.34	60
580	1.05	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Flood	22.2	29	2.89	54
581	1.10	200 feet off Fort Wadsworth	40 36 21	74 03 12	20	Flood	21.7	29	3.14	57
582	1.15	200 feet off Fort Wadsworth	40 36 21	74 03 12	40	Flood	21.4	27	4.94	88
583	2.25	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Flood	22.0	32	2.69	43
584	2.30	200 feet off Fort Lafayette	40 36 29	74 02 24	15	Flood	21.7	27	3.23	58
585	2.35	200 feet off Fort Lafayette	40 36 29	74 02 24	40	Flood	21.7	27	2.65	48

TABLE CXXV—Continued

16—NARROWS, CROSS SECTION, BETWEEN FORTS LAFAYETTE AND WADSWORTH. JULY 3, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
586	2.43	¼ way across	40 36 27	74 02 34	1	Flood	21.7	32	3.38	61
587	2.45	¼ way across	40 36 27	74 02 34	20	Flood	21.7	27	2.66	49
588	2.50	¼ way across	40 36 27	74 02 34	40	Flood	21.7	25	3.31	60
589	2.57	½ way across	40 36 25	74 02 48	1	Flood	22.2	33	3.07	56
590	3.00	½ way across	40 36 25	74 02 48	30	Flood	22.2	27	3.20	59
591	3.10	½ way across	40 36 25	74 02 48	60	Flood	21.2	33	3.30	59
592	3.12	¾ way across	40 36 23	74 03 02	1	Flood	22.2	33	3.64	66
593	3.15	¾ way across	40 36 23	74 03 02	20	Flood	21.2	29	3.73	67
594	3.24	¾ way across	40 36 23	74 03 02	40	Flood	21.2	27	3.80	68
595	3.30	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Flood	22.2	27	3.52	65
596	3.35	200 feet off Fort Wadsworth	40 36 21	74 03 12	20	Flood	21.2	24	3.74	68
597	3.40	200 feet off Fort Wadsworth	40 36 21	74 03 12	40	Flood	21.2	24	3.91	71
598	4.40	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Flood	22.2	25	4.04	75
599	4.46	200 feet off Fort Lafayette	40 36 29	74 02 24	15	Flood	21.1	24	3.67	66
600	4.53	200 feet off Fort Lafayette	40 36 29	74 02 24	30	Flood	21.1	24	3.67	66
601	5.00	¼ way across	40 36 27	74 02 34	1	Flood	22.2	27	3.47	64
602	5.03	¼ way across	40 36 27	74 02 34	20	Flood	21.1	28	3.67	66
603	5.10	¼ way across	40 36 27	74 02 34	40	Flood	22.2	27	4.26	78
604	5.20	½ way across	40 36 25	74 02 48	1	Flood	21.1	28	3.81	70
605	5.24	½ way across	40 36 25	74 02 48	30	Flood	22.2	27	3.30	60
606	5.26	½ way across	40 36 25	74 02 48	60	Flood	21.1	18	3.53	66
607	5.30	¾ way across	40 36 23	74 03 02	1	Flood	21.7	27	3.67	67
608	5.35	¾ way across	40 36 23	74 03 02	20	Flood	22.2	27	4.04	79
609	5.40	¾ way across	40 36 23	74 03 02	40	Flood	21.1	18	3.56	66
610	5.45	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Flood	22.2	27	3.70	69
611	5.50	200 feet off Fort Wadsworth	40 36 21	74 03 12	15	Flood	22.2	25	4.18	77
612	5.55	200 feet off Fort Wadsworth	40 36 21	74 03 12	30	Flood	21.1	25	4.56	83

17—EAST RIVER, BROOKLYN BRIDGE TO 118TH STREET. JULY 7, 1913

High water occurred at Governors Island at 12.35 P. M. Low water at 6.50 P. M. The wind was northwest, with a velocity of 5 miles per hour.

	P. M.									
613	1.35	Midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	22.0	29	2.62	48
614	1.40	Midstream, at Brooklyn Bridge	40 42 20	73 59 48	15	Ebb	22.0	29	1.84	33
615	1.45	Midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	22.0	29	1.87	34
616	1.53	Midstream, at Manhattan Bridge	40 42 25	73 59 28	1	Ebb	22.0	29	1.96	36
617	1.57	Midstream, at Manhattan Bridge	40 42 25	73 59 28	15	Ebb	22.2	29	2.44	44
618	2.00	Midstream, at Manhattan Bridge	40 42 25	73 59 28	30	Ebb	21.7	27	2.93	53
619	2.15	Entrance to Wallabout bay	40 42 30	73 58 15	1	Ebb	21.7	29	1.69	30
620	2.20	Entrance to Wallabout bay	40 42 30	73 58 15	15	Ebb	22.2	29	1.98	36
621	2.35	Entrance to Wallabout bay	40 42 30	73 58 15	30	Ebb	22.2	23	2.05	36
622	2.40	Midstream, at Williamsburg Bridge	40 42 49	73 58 21	1	Ebb	22.2	31	1.84	33
623	2.45	Midstream, at Williamsburg Bridge	40 42 49	73 58 21	15	Ebb	21.7	29	2.95	54
624	2.50	Midstream, at Williamsburg Vridge	40 42 49	73 58 21	30	Ebb	21.7	29	1.96	36
625	3.10	Midstream, opposite 23d street	40 44 00	73 58 05	1	Ebb	21.7	29	2.35	43
626	3.15	Midstream, opposite 23d street	40 44 00	73 58 05	15	Ebb	21.1	30	2.15	39
627	3.20	Midstream, opposite 23d street	40 44 00	73 58 05	30	Ebb	21.0	28	2.41	43
628	3.35	Opposite 42d street	40 44 50	73 57 55	1	Ebb	20.6	26	2.93	53
629	3.40	Opposite 42d street	40 44 50	73 57 55	15	Ebb	20.6	26	2.58	46
630	3.45	Opposite 42d street	40 44 50	73 57 55	30	Ebb	20.0	24	2.32	41
631	4.15	Blackwells Island Bridge	40 45 25	73 57 30	1	Ebb	20.0	24	1.65	30

TABLE CXXV—Continued

17—EAST RIVER, BROOKLYN BRIDGE TO 118TH STREET. JULY 7, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
632	4.20	Blackwells Island Bridge.............	40 45 25	73 57 30	15	Ebb	20.0	24	2.66	48
633	4.25	Blackwells Island Bridge.............	40 45 25	73 57 30	30	Ebb	20.0	24	2.56	44
634	4.55	At Mill Rock........................	40 46 50	73 56 25	1	Ebb	19.4	23	3.23	57
635	5.00	At Mill Rock........................	40 46 50	73 56 25	15	Ebb	18.8	23	3.92	69
636	5.05	At Mill Rock........................	40 46 50	73 56 25	30	Ebb	18.8	23	3.07	54
637	5.12	Harlem river, 109th street...........	40 47 23	73 56 07	1	Ebb	19.4	23	2.90	51
638	5.20	Harlem river, 109th street...........	40 47 23	73 56 07	15	Ebb	19.4	19	3.06	55
639	5.25	Harlem river, 109th street...........	40 47 23	73 56 07	25	Ebb	19.4	27	2.94	51
640	5.35	Harlem river, 118th street...........	40 47 41	73 55 44	1	Ebb	20.6	24	1.25	20
641	5.40	Harlem river, 118th street...........	40 47 41	73 55 44	12	Ebb	19.4	22	2.47	44
642	5.45	Harlem river, 118th street...........	40 47 41	73 55 44	20	Ebb	19.4	19	1.84	32

18—EAST RIVER, CROSS-SECTION, LAWRENCE POINT. JULY 8, 1913

Low water occurred at Governors Islanp at 7.30 A. M. High water at 1.20 P. M. The wind was northwest, with a velocity of 3 miles per hour.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	C. C. per litre	Per cent. saturation
643	A. M. 7.00	Lawrence Point, near black buoy.....	40 47 34	73 54 30	1	Flood	18.9	22	2.55	45
644	7.03	Lawrence Point, near black buoy.....	40 47 34	73 54 30	21	Flood	18.3	22	3.39	59
645	7.06	Lawrence Point, near black buoy.....	40 47 34	73 54 30	40	Flood	18.0	22	3.84	57
646	7.10	Mid-channel........................	40 47 25	73 54 31	1	Flood	18.0	22	3.39	59
647	7.12	Mid-channel........................	40 47 25	73 54 31	18	Flood	18.3	22	2.69	47
648	7.15	Mid-channel........................	40 47 25	73 54 31	35	Flood	18.3	22	3.42	59
649	7.20	200 feet off ferry, East 234th street...	40 47 56	73 54 31	1	Flood	18.3	20	3.13	54
650	7.25	200 feet off ferry, East 234th street...	40 47 56	73 54 31	15	Flood	17.8	22	2.66	46
651	7.30	200 feet off ferry, East 234th street...	40 47 56	73 54 31	30	Flood	17.8	20	2.99	51
652	8.20	Lawrence Point, near black buoy.....	40 47 34	73 54 30	1	Flood	18.3	20	3.19	55
653	8.23	Lawrence Point, near black buoy.....	40 47 34	73 54 30	21	Flood	18.3	22	3.29	57
654	8.25	Lawrence Point, near black buoy.....	40 47 34	73 54 30	40	Flood	18.3	26	4.12	71
655	8.33	Mid-channel........................	40 47 25	73 54 31	1	Flood	18.3	24	4.18	72
656	8.36	Mid-channel........................	40 47 25	73 54 31	18	Flood	18.6	24	3.69	64
657	8.40	Mid-channel........................	40 47 25	73 54 31	35	Flood	18.6	24	4.41	76
658	8.45	200 feet off ferry, East 234th street...	40 47 56	73 54 31	1	Flood	18.3	24	3.46	60
659	8.48	200 feet off ferry, East 234th street...	40 47 56	73 54 31	15	Flood	18.3	24	3.37	58
660	8.55	200 feet off ferry, East 234th street...	40 47 56	73 54 31	30	Flood	18.3	24	3.03	52
661	9.55	Lawrence Point, near buoy...........	40 47 34	73 54 30	1	Flood	20.0	24	2.35	42
662	10.03	Lawrence Point, near buoy...........	40 47 34	73 54 30	21	Flood	20 0	24	2.58	46
663	10.06	Lawrence Point, near buoy...........	40 47 34	73 54 30	40	Flood	18.9	30	2.88	41
664	10.10	Mid-channel........................	40 47 25	73 54 31	1	Flood	20.0	24	2.62	47
665	10.15	Mid-channel........................	40 47 25	73 54 31	18	Flood	19.4	30	1.88	33
666	10.20	Mid-channel........................	40 47 25	73 54 31	35	Flood	19.4	30	2.14	37
667	10.25	200 feet off ferry house, E. 234th st...	40 47 56	73 54 31	1	Flood	19.7	24	2.17	38
668	10.30	200 feet off ferry house, E. 234th st...	40 47 56	73 54 31	15	Flood	19.7	30	1.84	32
669	10.35	200 feet off ferry house, E. 234th st...	40 47 56	73 54 31	30	Flood	19.7	30	2.83	49
670	11.50	Lawrence Point, near black buoy.....	40 47 34	73 54 30	1	Flood	21.1	30	1.48	26
671	11.55	Lawrence Point, near black buoy.....	40 47 34	73 54 30	21	Flood	21.4	30	1.38	25
672	12.00	Lawrence Point, near black buoy.....	40 47 34	73 54 30	40	Flood	21.7	30	1.75	32
673	P. M. 12.05	Mid-channel........................	40 47 25	73 54 31	1	Flood	21.7	30	1.97	35
674	12.08	Mid-channel........................	40 47 25	73 54 31	18	Flood	22.2	29	1.37	25

TABLE CXXV—Continued

18—EAST RIVER, CROSS-SECTION, LAWRENCE POINT. JULY 8, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
675	12.11	Mid-channel	40 47 25	73 54 31	35	Flood	21.7	33	2.26	47
676	12.15	200 feet off ferry house, E. 234th st.	40 47 56	73 54 31	1	Flood	22.8	32	2.20	47
677	12.20	200 feet off ferry house, E. 234th st.	40 47 56	73 54 31	15	Flood	22.8	32	1.63	32
678	12.25	200 feet off ferry house, E. 234th st.	40 47 56	73 54 31	30	Flood	21.7	30	2.74	51
679	1.53	Lawrence Point, near buoy	40 47 34	73 54 30	1	Ebb	21.7	32	1.74	31
680	1.56	Lawrence Point, near buoy	40 47 34	73 54 30	21	Ebb	21.7	32	1.78	32
681	2.00	Lawrence Point, near buoy	40 47 34	73 54 30	40	Ebb	21.7	29	2.52	45
682	2.05	Mid-channel	40 47 25	73 54 31	1	Ebb	22.0	32	2.13	38
683	2.10	Mid-channel	40 47 25	73 54 31	18	Ebb	21.7	32	1.87	34
684	2.15	Mid-channel	40 47 25	73 54 31	35	Ebb	21.7	32	1.67	30
685	2.20	200 feet off ferry house, E. 234th st.	40 47 56	73 54 31	1	Ebb	21.7	32	1.85	34
686	2.25	200 feet off ferry house, E. 234th st.	40 47 56	73 54 31	15	Ebb	21.7	25	1.62	30
687	2.30	200 feet off ferry house, E. 234th st.	40 47 56	73 54 31	30	Ebb	21.4	25	1.95	35
688	4.08	Lawrence Point, near buoy	40 47 34	73 54 30	1	Ebb	20.0	25	2.85	50
689	4.15	Lawrence Point, near buoy	40 47 34	73 54 30	21	Ebb	20.0	25	2.79	48
690	4.17	Lawrence Point, near buoy	40 47 34	73 54 30	40	Ebb	20.0	25	2.48	44
691	4.20	Mid-channel	40 47 25	73 54 31	1	Ebb	19.7	22	2.99	53
692	4.25	Mid-channel	40 47 25	73 54 31	18	Ebb	19.7	22	2.99	53
693	4.30	Mid-channel	40 47 25	73 54 31	35	Ebb	19.7	22	3.11	55
694	4.37	200 feet off ferry, East 234th street	40 47 56	73 54 31	1	Ebb	19.1	22	2.93	51
695	4.40	200 feet off ferry, East 234th street	40 47 56	73 54 31	15	Ebb	19.4	22	3.68	65
696	4.45	200 feet off ferry, East 234th street	40 47 56	73 54 31	30	Ebb	19.4	22	3.42	60
697	5.25	Lawrence Point, near buoy	40 47 34	73 54 30	1	Ebb	18.9	26	2.55	44
698	5.30	Lawrence Point, near buoy	40 47 34	73 54 30	21	Ebb	19.4	22	2.89	51
699	5.35	Lawrence Point, near buoy	40 47 34	73 54 30	40	Ebb	19.2	19	3.66	65
700	5.40	Mid-channel	40 47 25	73 54 31	1	Ebb	19.2	23	3.77	66
701	5.43	Mid-channel	40 47 25	73 54 31	15	Ebb	19.2	23	4.20	73
702	5.45	Mid-channel	40 47 25	73 54 31	30	Ebb	18.9	23	3.49	60
703	5.52	200 feet off ferry, East 234th street	40 47 56	73 54 31	1	Ebb	18.9	23	3.43	60
704	5.55	200 feet off ferry, East 234th street	40 47 56	73 54 31	15	Ebb	18.9	23	3.42	60
705	5.59	200 feet off ferry, East 234th street	40 47 56	73 54 31	30	Ebb	18.9	22	3.42	60

19—HUDSON RIVER, CROSS-SECTION, PIER A TO C. R.R. OF N. J. PIER. JULY 9, 1913

Low water occurred at Governors Island at 8.30 A. M. High water at 2.45 P. M. The wind was southwest, with a velocity of 3 miles per hour.

	A. M.									
706	7.10	100 feet off Pier A	40 42 16	74 01 09	1	Flood	21.7	27	2.63	48
707	7.15	100 feet off Pier A	40 42 16	74 01 09	18	Flood	21.7	27	2.41	53
708	7.20	100 feet off Pier A	40 42 16	74 01 09	30	Flood	21.1	27	2.66	49
709	7.25	¼ way across	40 42 17	74 01 20	1	Flood	21.7	27	2.60	47
710	7.30	¼ way across	40 42 17	74 01 20	18	Flood	21.7	29	2.21	39
711	7.35	¼ way across	40 42 17	74 01 20	30	Flood	21.7	32	1.97	36
712	7.38	½ way across	40 42 19	74 01 34	1	Flood	21.7	33	2.19	39
713	7.42	½ way across	40 42 19	74 01 34	18	Flood	21.7	32	1.97	36
714	7.46	½ way across	40 42 19	74 01 34	42	Flood	21.7	32	2.04	37
715	7.49	¾ way across	40 42 21	74 01 48	1	Flood	21.9	33	2.22	40
716	7.53	¾ way across	40 42 21	74 01 48	18	Flood	21.9	33	2.48	45
717	7.58	¾ way across	40 42 21	74 01 48	42	Flood	21.7	33	2.36	43
718	8.00	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	1	Flood	21.9	35	2.28	41
719	8.05	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	18	Flood	21.1	35	2.60	46
720	8.10	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	30	Flood	21.1	34	2.40	42

TABLE CXXV—Continued

19—HUDSON RIVER, CROSS-SECTION, PIER A TO C. R.R. OF N. J. PIER. JULY 9, 1913—Continued

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
721	9.30	100 feet off Pier A	40 42 16	74 01 09	1	Flood	22.2	35	2.26	40
722	9.35	100 feet off Pier A	40 42 16	74 01 09	18	Flood	21.7	33	2.20	40
723	9.38	100 feet off Pier A	40 42 16	74 01 09	30	Flood	21.1	28	2.33	42
724	9.42	¼ way across	40 42 17	74 01 20	1	Flood	21.9	33	2.21	40
725	9.45	¼ way across	40 42 17	74 01 20	18	Flood	21.9	33	1.81	33
726	9.50	¼ way across	40 42 17	74 01 20	30	Flood	21.7	32	1.89	34
727	9.55	½ way across	40 42 19	74 01 34	1	Flood	22.2	35	2.41	44
728	10.00	½ way across	40 42 19	74 01 34	18	Flood	21.7	35	2.38	43
729	10.05	½ way across	40 42 19	74 01 34	42	Flood	21.1	32	2.04	37
730	10.08	¾ way across	40 42 21	74 01 48	1	Flood	22.2	35	2.23	40
731	10.10	¾ way across	40 42 21	74 01 48	18	Flood	21.7	35	2.78	50
732	10.15	¾ way across	40 42 21	74 01 48	42	Flood	21.7	32	2.67	48
733	10.20	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	1	Flood	21.9	33	2.39	43
734	10.25	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	18	Flood	21.9	32	2.20	40
735	10.30	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	30	Flood	21.9	32	2.74	50
736	11.25	100 feet off Pier A	40 42 16	74 01 09	1	Flood	22.2	33	2.76	50
737	11.30	100 feet off Pier A	40 42 16	74 01 09	18	Flood	21.7	32	2.03	37
738	11.33	100 feet off Pier A	40 42 16	74 01 09	30	Flood	21.1	30	2.35	42
739	11.35	¼ way across	40 42 17	74 01 20	1	Flood	21.7	35	2.12	38
740	11.37	¼ way across	40 42 17	74 01 20	18	Flood	21.7	32	2.02	36
741	11.42	¼ way across	40 42 17	74 01 20	30	Flood	21.4	30	1.39	25
742	11.47	½ way across	40 42 19	74 01 34	1	Flood	21.7	32	2.35	42
743	11.50	½ way across	40 42 19	74 01 34	18	Flood	21.7	32	2.37	43
744	11.55	½ way across	40 42 19	74 01 34	42	Flood	20.8	30	1.94	34
745	12.00 P. M.	¾ way across	40 42 21	74 01 48	1	Ebb	21.7	32	2.65	46
746	12.05	¾ way across	40 42 41	74 01 48	18	Ebb	21.7	32	2.70	48
747	12.07	¾ way across	40 42 21	74 01 48	42	Ebb	21.4	30	2.80	52
748	12.10	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	1	Ebb	21.7	32	2.05	37
749	12.15	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	18	Ebb	21.7	30	2.36	43
750	12.20	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	30	Ebb	21.7	30	2.56	46
751	1.35	100 feet off Pier A	40 42 16	74 01 09	1	Ebb	21.1	24	2.93	53
752	1.40	100 feet off Pier A	40 42 16	74 01 09	18	Ebb	20.8	24	3.23	58
753	1.45	100 feet off Pier A	40 42 16	74 01 09	30	Ebb	20.3	21	2.93	53
754	1.50	¼ way across	40 42 17	74 01 20	1	Ebb	21.4	27	3.90	71
755	1.53	¼ way across	40 42 17	74 01 20	18	Ebb	20.8	24	3.31	59
756	1.56	¼ way across	40 42 17	74 01 20	30	Ebb	20.0	19	3.31	59
757	2.05	½ way across	40 42 19	74 01 34	1	Ebb	21.4	26	3.08	50
758	2.10	½ way across	40 42 19	74 01 34	18	Ebb	20.8	24	3.25	59
759	2.12	½ way across	40 42 19	74 01 34	42	Ebb	20.3	19	3.95	71
760	2.20	¾ way across	40 42 21	74 01 48	1	Ebb	21.7	27	3.29	60
761	2.24	¾ way across	40 42 21	74 01 48	18	Ebb	20.8	26	3.46	62
762	2.30	¾ way across	40 42 21	74 01 48	42	Ebb	20.3	21	3.91	70
763	2.35	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	1	Ebb	21.7	29	2.79	51
764	2.40	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	18	Ebb	21.4	32	3.00	54
765	2.45	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	30	Ebb	20.6	30	3.95	70
766	4.00	100 feet off Pier A	40 42 16	74 01 09	1	Ebb	21.1	32	3.91	70
767	4.03	100 feet off Pier A	40 42 16	74 01 09	18	Ebb	20.8	24	3.29	59
768	4.08	100 feet off Pier A	40 42 16	74 01 09	30	Ebb	21.1	24	3.55	63
769	4.10	¼ way across	40 42 17	74 01 20	1	Ebb	20.6	24	3.86	70
770	4.15	¼ way across	40 42 17	74 01 20	18	Ebb	20.6	24	3.46	62
771	4.18	¼ way across	40 42 17	74 01 20	30	Ebb	21.1	22	3.75	67

TABLE CXXV—Continued

19—HUDSON RIVER, CROSS-SECTION, PIER A TO C. R.R. OF N. J. PIER. JULY 9, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
772	4.22	½ way across	40 42 19	74 01 34	1	Ebb	20.8	26	2.86	52
773	4.25	½ way across	40 42 19	74 01 34	18	Ebb	20.8	24	3.16	57
774	4.30	½ way across	40 42 19	74 01 34	42	Ebb	21.1	26	2.57	46
775	4.33	¾ way across	40 42 21	74 01 48	1	Ebb	21.1	28	3.09	55
776	4.36	¾ way across	40 42 21	74 01 48	18	Ebb	21.1	26	3.03	55
777	4.38	¾ way across	40 42 21	74 01 48	42	Ebb	20.6	24	2.74	50
778	4.40	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	1	Ebb	21.1	26	2.08	38
779	4.45	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	18	Ebb	21.1	26	2.70	48
780	4.50	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	30	Ebb	20.6	24	3.22	57
781	5.35	100 feet off Pier A	40 42 16	74 01 09	1	Ebb	21.1	28	3.49	63
782	5.38	100 feet off Pier A	40 42 16	74 01 09	18	Ebb	21.1	28	3.83	69
783	5.40	100 feet off Pier A	40 42 16	74 01 09	30	Ebb	21.1	28	3.46	62
784	5.45	¼ way across	40 42 17	74 01 20	1	Ebb	21.1	28	2.41	53
785	5.47	¼ way across	40 42 17	74 01 20	18	Ebb	20.8	26	2.71	49
786	5.50	¼ way across	40 42 17	74 01 20	30	Ebb	20.8	26	2.31	41
787	5.55	½ way across	40 42 19	74 01 34	1	Ebb	21.1	28	3.25	58
788	5.58	½ way across	40 42 19	74 01 34	18	Ebb	21.1	28	2.74	49
789	6.00	½ way across	40 42 19	74 01 34	42	Ebb	20.6	24	2.46	44
790	6.05	¾ way across	40 42 21	74 01 48	1	Ebb	21.1	28	2.09	38
791	6.07	¾ way across	40 42 21	74 01 48	18	Ebb	21.1	28	3.02	54
792	6.10	¾ way across	40 42 21	74 01 48	42	Ebb	20.6	24	2.42	43
793	6.20	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	1	Ebb	20.8	26	2.40	43
794	6.22	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	18	Ebb	20.8	26	2.90	52
795	6.25	100 feet off C. R.R. of N. J. pier	40 42 22	74 01 59	30	Ebb	20.6	20	2.84	51

20—ROBBINS REEF. JULY 10, 1913

High water occurred at Governors Island at 4.10 P. M. Low water at 9.30 A. M. The wind was west, with a velocity of 5 miles per hour.

	A. M.									
796	7.20	Near bell buoy	40 39 15	74 03 50	1	Flood	20.8	24	3.16	57
797	7.25	Near bell buoy	40 39 15	74 03 50	24	Flood	20.6	27	3.13	56
798	7.30	Near bell buoy	40 39 15	74 03 50	48	Flood	20.6	25	3.61	65
799	8.20	Near bell buoy	40 39 15	74 03 50	1	Flood	20.8	26	2.80	50
800	8.25	Near bell buoy	40 39 15	74 03 50	24	Flood	20.8	24	2.90	52
801	8.30	Near bell buoy	40 39 15	74 03 50	48	Flood	20.6	20	3.00	54
802	9.05	Near bell buoy	40 39 15	74 03 50	1	Flood	21.1	26	2.50	45
803	9.10	Near bell buoy	40 39 15	74 03 50	24	Flood	21.1	26	3.20	57
804	9.15	Near bell buoy	40 39 15	74 03 50	48	Flood	20.6	24	3.20	57
805	11.00	Near bell buoy	40 39 15	74 03 50	1	Flood	20.8	22	2.50	45
806	11.10	Near bell buoy	40 39 15	74 03 50	24	Flood	20.6	20	2.60	46
807	11.15	Near bell buoy	40 39 15	74 03 50	48	Flood	19.4	15	3.80	69
	P. M.									
808	1.00	Near bell buoy	40 39 15	74 03 50	1	Flood	20.6	18	2.60	47
809	1.05	Near bell buoy	40 39 15	74 03 50	28	Flood	19.7	17	3.90	70
810	1.10	Near bell buoy	40 39 15	74 03 50	48	Flood	19.7	17	4.10	74
811	1.55	Near bell buoy	40 39 15	74 03 50	1	Ebb	20.8	16	4.30	79
812	2.00	Near bell buoy	40 39 15	74 03 50	24	Ebb	20.0	16	4.40	80
813	2.05	Near bell buoy	40 39 15	74 03 50	48	Ebb	19.7	15	4.10	74
814	3.00	Near bell buoy	40 39 15	74 03 50	1	Ebb	20.6	16	4.30	79
815	3.05	Near bell buoy	40 39 15	74 03 50	24	Ebb	19.7	15	4.30	77

TABLE CXXV—Continued

20—ROBBINS REEF. JULY 10, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
816	3.10	Near bell buoy....................	40 39 15	74 03 50	48	Ebb	19.7	15	4.40	80
817	4.00	Near bell buoy....................	40 39 15	74 03 50	1	Ebb	20.6	16	4.30	79
818	4.05	Near bell buoy....................	40 39 15	74 03 50	24	Ebb	20.3	16	4.80	88
819	4.10	Near bell buoy....................	40 39 15	74 03 50	48	Ebb	19.7	15	4.60	82
820	5.50	Near bell buoy....................	40 39 15	74 03 50	1	Ebb	21.1	15	4.20	78
821	5.55	Near bell buoy....................	40 39 15	74 03 50	24	Ebb	20.0	15	4.60	83
822	6.00	Near bell buoy....................	40 39 15	74 03 50	48	Ebb	20.0	13	4.70	86

21—KILL VAN KULL, CROSS-SECTION, SAILORS SNUG HARBOR. JULY 11, 1913

Low water occurred at Governors Island at 10.30 A. M. High water at 3.00 P. M. The wind was northwest, with a velocity of 3 miles per hour.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	C. C. per litre	Per cent. saturation
823	A. M. 7.30	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	1	Ebb	21.1	28	3.40	61
824	7.35	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	15	Ebb	21.1	28	4.10	74
825	7.40	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	24	Ebb	21.1	30	3.50	63
826	7.45	Midstream........................	40 38 51	74 06 08	1	Ebb	21.1	30	3.98	71
827	7.50	Midstream........................	40 38 51	74 06 08	15	Ebb	21.1	30	3.40	61
828	7.55	Midstream........................	40 38 51	74 06 08	30	Ebb	21.1	30	3.37	60
829	8.00	200 feet off Bayonne shore...........	40 38 55	74 06 07	1	Flood	20.8	30	4.11	73
830	8.05	200 feet off Bayonne shore...........	40 38 55	74 06 07	15	Flood	21.1	28	3.73	67
831	8.10	200 feet off Bayonne shore...........	40 38 55	74 06 07	24	Flood	21.7	30	4.09	73
832	9.05	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	1	Flood	21.7	32	4.10	74
833	9.08	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	15	Flood	21.4	29	3.80	69
834	9.12	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	24	Flood	21.7	29	3.80	69
835	9.19	Midstream........................	40 38 51	74 06 08	1	Flood	21.7	32	3.98	71
836	9.22	Midstream........................	40 38 51	74 06 08	15	Flood	21.7	29	3.90	70
837	9.30	Midstream........................	40 38 51	74 06 08	30	Flood	21.7	29	3.99	72
838	9.35	200 feet off Bayonne shore...........	40 38 55	74 06 07	1	Flood	21.7	29	4.20	76
839	9.38	200 feet off Bayonne shore...........	40 38 55	74 06 07	15	Flood	21.9	29	3.54	64
840	9.45	200 feet off Bayonne shore...........	40 38 55	74 06 07	24	Flood	21.7	29	4.09	74
841	11.00	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	1	Flood	21.7	25	3.10	57
842	11.05	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	15	Flood	21.7	24	3.40	62
843	11.08	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	24	Flood	21.4	25	3.40	62
844	11.10	Midstream........................	40 38 51	74 06 08	1	Flood	21.7	28	3.19	58
845	11.17	Midstream........................	40 38 51	74 06 08	15	Flood	21.1	28	2.99	54
846	11.20	Midstream........................	40 38 51	74 06 08	30	Flood	21.7	28	3.24	58
847	11.25	200 feet off Bayonne shore...........	40 38 55	74 06 07	1	Flood	21.7	27	3.46	63
848	11.30	200 feet off Bayonne shore...........	40 38 55	74 06 07	15	Flood	21.7	27	3.02	55
849	11.35	200 feet off Bayonne shore...........	40 38 55	74 06 07	24	Flood	21.7	27	3.75	68
850	P. M. 1.00	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	1	Flood	21.9	29	3.00	55
851	1.05	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	15	Flood	21.4	29	3.30	60
852	1.10	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	24	Flood	21.7	25	3.80	69
853	1.15	Midstream........................	40 38 51	74 06 08	1	Flood	21.7	29	3.19	55
854	1.18	Midstream........................	40 38 51	74 06 08	15	Flood	21.1	28	3.30	60
855	1.20	Midstream........................	40 38 51	74 06 08	30	Flood	20.6	24	3.14	56
856	1.25	200 feet off Bayonne shore...........	40 38 55	74 06 07	1	Flood	21.7	27	3.43	62
857	1.28	200 feet off Bayonne shore...........	40 38 55	74 06 7	15	Flood	21.1	25	3.30	60
858	1.30	200 feet off Bayonne shore...........	40 38 55	74 06 07	24	Flood	20.6	24	3.93	70
859	2.10	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	1	Ebb	21.1	26	3.30	59

TABLE CXXV—Continued

21—KILL VAN KULL, CROSS-SECTION, SAILORS SNUG HARBOR. JULY 11, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. satura-tion
			° ′ ″	° ′ ″						
860	2.12	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	15	Ebb	20.6	22	3.70	66
861	2.15	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	24	Ebb	20.6	22	3.70	66
862	2.25	Mid-channel......................	40 38 51	74 06 08	1	Ebb	21.1	26	3.47	62
863	2.30	Mid-channel......................	40 38 51	74 06 08	15	Ebb	20.6	20	3.80	69
864	2.33	Mid-channel......................	40 38 51	74 06 08	30	Ebb	20.0	21	4.27	76
865	2.36	200 feet off Bayonne shore...........	40 38 55	74 06 07	1	Ebb	21.1	26	4.01	70
866	2.38	200 feet off Bayonne shore...........	40 38 55	74 06 07	15	Ebb	20.6	24	3.33	60
867	2.40	200 feet off Bayonne shore...........	40 38 55	74 06 07	24	Ebb	20.0	24	3.70	66
868	3.15	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	1	Ebb	20.3	18	3.80	70
869	3.17	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	15	Ebb	20.0	17	3.70	67
870	3.20	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	24	Ebb	20.0	18	3.60	65
871	3.25	Mid-channel......................	40 38 51	74 06 08	1	Ebb	20.6	20	3.69	66
872	3.30	Mid-channel......................	40 38 51	74 06 08	15	Ebb	20.6	20	3.30	60
873	3.35	Mid-channel......................	40 38 51	74 06 08	30	Ebb	20.0	17	3.59	63
874	3.40	200 feet off Bayonne shore...........	40 38 55	74 06 07	1	Ebb	21.1	20	3.21	59
875	3.45	200 feet off Bayonne shore...........	40 38 55	74 06 07	15	Ebb	20.6	20	3.41	62
876	3.50	200 feet off Bayonne shore...........	40 38 55	74 06 07	24	Ebb	20.0	18	3.91	70
877	4.50	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	1	Ebb	21.7	21	3.50	68
878	4.53	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	15	Ebb	20.6	20	3.60	65
879	4.55	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	24	Ebb	20.6	18	4.00	71
880	5.05	Mid-channel......................	40 38 51	74 06 08	1	Ebb	21.1	24	3.29	57
881	5.08	Mid-channel......................	40 38 51	74 06 08	15	Ebb	21.1	24	3.80	69
882	5.11	Mid-channel......................	40 38 51	74 06 08	30	Ebb	20.8	22	3.54	64
883	5.15	200 feet off Bayonne shore...........	40 38 55	74 06 07	1	Ebb	21.7	27	4.08	72
884	5.20	200 feet off Bayonne shore...........	40 38 55	74 06 07	15	Ebb	21.1	25	3.31	59
885	5.25	200 feet off Bayonne shore...........	40 38 55	74 06 07	24	Ebb	21.1	25	4.24	77
886	6.15	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	1	Ebb	21.9	27	3.20	58
887	6.20	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	15	Ebb	21.7	26	3.20	58
888	6.25	200 feet off Sailors Snug Harbor......	40 38 46	74 06 09	24	Ebb	21.7	26	4.10	74
889	6.28	Mid-channel......................	40 38 51	74 06 08	1	Ebb	22.2	31	3.66	67
890	6.30	Mid-channel......................	40 38 51	74 06 08	15	Ebb	21.7	31	3.40	61
891	6.35	Mid-channel......................	40 38 51	74 06 08	30	Ebb	21.7	30	3.79	68
892	6.40	200 feet off Bayonne shore...........	40 38 55	74 06 07	1	Ebb	21.7	30	3.51	63
893	6.45	200 feet off Bayonne shore...........	40 38 55	74 06 07	15	Ebb	21.7	30	3.59	65
894	6.50	200 feet off Bayonne shore...........	40 38 55	74 06 07	24	Ebb	21.7	30	3.89	70

22—EAST RIVER, CROSS SECTION, THROGS NECK TO CRYDERS POINT LANDING. JULY 14, 1913

High water occurred at Governors Island at 6.20 P. M. Low water at 11.50 A. M. The wind was west, with a velocity of 3 to 40 miles per hour.

	A. M.									
895	7.25	300 feet off landing, west of light.....	40 48 27	73 48 16	1	Ebb	18.9	22	3.80	66
896	7.30	300 feet off landing, west of light.....	40 48 27	73 48 16	18	Ebb	18.3	18	4.00	70
897	7.35	300 feet off landing, west of light.....	40 48 27	73 48 16	42	Ebb	18.3	18	4.40	77
898	7.40	¼ way across......................	40 48 20	73 48 18	1	Ebb	18.3	18	4.09	72
899	7.45	¼ way across......................	40 48 20	73 48 18	18	Ebb	18.3	18	4.61	81
900	7.50	¼ way across......................	40 48 20	73 48 18	48	Ebb	18.3	18	5.30	93
901	7.52	½ way across......................	40 48 09	73 48 21	1	Ebb	18.9	18	4.90	86
902	7.56	½ way across......................	40 48 09	73 48 21	24	Ebb	18.9	18	4.75	84
903	7.59	½ way across......................	40 48 09	73 48 21	48	Ebb	18.3	18	4.38	77
904	8.02	¾ way across......................	40 47 58	73 48 24	1	Ebb	18.9	18	4.36	77
905	8.05	¾ way across......................	40 47 58	73 48 24	24	Ebb	18.9	18	4.56	80

TABLE CXXV—Continued

22—EAST RIVER, CROSS SECTION, THROGS NECK TO CRYDERS POINT LANDING. JULY 14, 1913—Continued

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
906	8.12	¾ way across	40 47 58	73 48 24	48	Ebb	18.3	19	5.21	91
907	8.15	300 feet off landing, Cryders Point	40 47 50	73 48 28	1	Ebb	18.3	19	4.76	84
908	8.20	300 feet off landing, Cryders Point	40 47 50	73 48 28	24	Ebb	18.3	21	4.26	75
909	8.25	300 feet off landing, Cryders Point	40 47 50	73 48 28	42	Ebb	18.3	21	4.69	81
910	9.45	300 feet off landing, west of light	40 48 27	73 48 16	1	Ebb	18.9	18	4.70	83
911	9.50	300 feet off landing, west of light	40 48 27	73 48 16	18	Ebb	18.3	18	4.90	86
912	9.55	300 feet off landing, west of light	40 48 27	73 48 16	42	Ebb	18.0	18	4.70	82
913	10.00	¼ way across	40 48 20	73 48 18	1	Ebb	18.6	18	4.80	84
914	10.05	¼ way across	40 48 20	73 48 18	18	Ebb	18.3	18	5.61	98
915	10.08	¼ way across	40 48 20	73 48 18	48	Ebb	18.3	18	5.00	88
916	10.10	½ way across	40 48 09	73 48 21	1	Ebb	18.3	18	4.45	78
917	10.15	½ way across	40 48 09	73 48 21	18	Ebb	18.3	18	4.97	87
918	10.18	½ way across	40 48 09	73 48 21	48	Ebb	18.0	18	5.69	98
919	10.20	¾ way across	40 47 58	73 48 24	1	Ebb	18.9	18	4.55	80
920	10.25	¾ way across	40 47 58	73 48 24	18	Ebb	18.3	18	5.00	87
921	10.30	¾ way across	40 47 58	73 48 24	48	Ebb	18.3	18	5.15	90
922	10.35	300 feet off landing, Cryders Point	40 47 50	73 48 28	1	Ebb	18.9	18	3.51	61
923	10.40	300 feet off landing, Cryders Point	40 47 50	73 48 28	18	Ebb	18.3	18	4.65	81
924	10.45	300 feet off landing, Cryders Point	40 47 50	73 48 28	42	Ebb	18.0	18	4.48	78
925	P. M. 12.25	300 feet off landing, west of light	40 48 27	73 48 16	1	Ebb	20.0	21	4.90	88
926	12.30	300 feet off landing, west of light	40 48 27	73 48 16	18	Ebb	19.4	21	4.90	87
927	12.33	300 feet off landing, west of light	40 48 27	73 48 16	42	Ebb	18.9	20	4.60	81
928	12.35	¼ way across	40 48 20	73 48 18	1	Slack	19.4	21	4.79	85
929	12.40	¼ way across	40 48 20	73 48 18	18	Slack	18.9	20	4.50	79
930	12.45	¼ way across	40 48 20	73 48 18	48	Slack	18.9	20	5.00	88
931	12.50	½ way across	40 48 09	73 48 21	1	Slack	20.1	20	4.05	71
932	12.55	½ way across	40 48 09	73 48 21	18	Slack	18.9	20	4.97	88
933	1.00	½ way across	40 48 09	73 48 21	48	Slack	18.3	20	4.84	85
934	1.05	¾ way across	40 47 58	73 48 24	1	Slack	18.9	22	4.36	76
935	1.10	¾ way across	40 47 58	73 48 24	18	Slack	18.9	20	4.90	87
936	1.15	¾ way across	40 47 58	73 48 24	48	Slack	18.3	20	5.55	96
937	1.17	300 feet off landing, Cryders Point	40 47 50	73 48 28	1	Slack	18.9	17	3.92	66
938	1.22	300 feet off landing, Cryders Point	40 47 50	73 48 28	18	Slack	18.3	16	4.40	78
939	1.27	300 feet off landing, Cryders Point	40 47 50	73 48 28	42	Slack	18.3	16	4.48	79
940	2.35	300 feet off landing, west of light	40 48 27	73 48 16	1	Flood	18.9	18	5.00	88
941	2.40	300 feet off landing, west of light	40 48 27	73 48 16	18	Flood	18.6	18	4.70	82
942	2.44	300 feet off landing, west of light	40 48 27	73 48 16	42	Flood	18.6	18	4.30	75
943	2.48	¼ way across	40 48 20	73 48 18	1	Flood	19.4	21	4.78	84
944	2.51	¼ way across	40 48 20	73 48 18	18	Flood	19.1	21	4.20	74
945	2.55	¼ way across	40 48 20	73 48 18	48	Flood	19.1	18	5.20	92
946	2.58	½ way across	40 48 09	73 48 21	1	Flood	18.9	20	4.44	78
947	3.02	½ way across	40 48 09	73 48 21	18	Flood	18.3	20	4.68	82
948	3.07	½ way across	40 48 09	73 48 21	48	Flood	18.3	20	4.46	78
949	3.15	¾ way across	40 47 58	73 48 24	1	Flood	19.4	21	4.75	84
950	3.20	¾ way across	40 47 58	73 48 24	18	Flood	18.9	20	4.29	76
951	3.25	¾ way across	40 47 58	73 48 24	48	Flood	18.9	18	4.96	87
952	3.30	300 feet off landing, Cryders Point	40 47 50	73 48 28	1	Flood	20.0	19	3.48	60
953	3.35	300 feet off landing, Cryders Point	40 47 50	73 48 28	18	Flood	19.4	19	5.00	89
954	3.40	300 feet off landing, Cryders Point	40 47 50	73 48 28	42	Flood	19.1	17	4.51	80
955	4.45	300 feet off landing, west of light	40 48 27	73 48 16	1	Flood	20.0	19	4.50	81
956	4.47	300 feet off landing, west of light	40 48 27	73 48 16	18	Flood	19.7	19	4.70	84

TABLE CXXV—Continued

22—EAST RIVER, CROSS SECTION, THROGS NECK TO CRYDERS POINT LANDING. JULY 14, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
957	4.55	300 feet off landing, west of light.....	40 48 27	73 48 16	42	Flood	19.4	19	4.60	82
958	4.58	¼ way across.....................	40 48 20	73 48 18	1	Flood	19.7	21	4.00	71
959	4.59	¼ way across.....................	40 48 20	73 48 18	18	Flood	19.4	21	3.90	70
960	5.01	¼ way across.....................	40 48 20	73 48 18	48	Flood	18.9	19	4.40	77
961	5.05	½ way across.....................	40 48 09	73 48 21	1	Flood	19.4	21	3.79	67
962	5.10	½ way across.....................	40 48 09	73 48 21	18	Flood	18.9	19	4.47	79
963	5.15	½ way across.....................	40 48 09	73 48 21	48	Flood	18.9	19	4.46	78
964	5.18	¾ way across.....................	40 47 58	73 48 24	1	Flood	18.9	21	4.26	75
965	5.20	¾ way across.....................	40 47 58	73 48 24	18	Flood	18.9	21	4.87	85
966	5.22	¾ way across.....................	40 47 58	73 48 24	48	Flood	18.6	18	4.96	87
967	5.25	300 feet off landing, Cryders Point....	40 47 50	73 48 28	1	Flood	18.9	21	3.76	66
968	5.30	300 feet off landing, Cryders Point....	40 47 50	73 48 28	18	Flood	18.9	21	4.34	76
969	5.35	300 feet off landing, Cryders Point....	40 47 50	73 48 28	42	Flood	18.3	18	4.00	70
970	6.10	300 feet off landing, west of light.....	40 48 27	73 48 16	1	Flood	19.4	21	4.20	74
971	6.13	300 feet off landing, west of light.....	40 48 27	73 48 16	18	Flood	18.9	21	4.00	70
972	6.18	300 feet off landing, west of light.....	40 48 27	73 48 16	42	Flood	18.3	22	3.90	68
973	6.20	¼ way across.....................	40 48 20	73 48 18	1	Flood	19.4	21	4.38	75
974	6.22	¼ way across.....................	40 48 20	73 48 18	18	Flood	18.9	21	3.90	67
975	6.25	¼ way across.....................	40 48 20	73 48 18	48	Flood	18.9	21	4.11	72
976	6.26	½ way across.....................	40 48 09	73 48 21	1	Slack	18.9	21	3.63	64
977	6.28	½ way across.....................	40 48 09	73 48 21	18	Slack	18.9	21	4.16	73
978	6.30	½ way across.....................	40 48 09	73 48 21	48	Slack	18.3	20	4.27	74
979	6.35	¾ way across.....................	40 47 58	73 48 24	1	Slack	18.9	21	4.56	80
980	6.40	¾ way across.....................	40 47 58	73 48 24	18	Slack	18.9	21	4.80	85
981	6.45	¾ way across.....................	40 47 58	73 48 24	48	Slack	18.9	20	4.86	88
982	6.47	300 feet off landing, Cryders Point....	40 47 50	73 48 28	1	Slack	18.9	21	3.30	60
983	6.50	300 feet off landing, Cryders Point....	40 47 50	73 48 28	18	Slack	18.9	21	4.64	82
984	6.55	300 feet off landing, Cryders Point....	40 47 50	73 48 28	42	Slack	18.9	20	4.40	77

23—HARLEM RIVER, WILLIS AVENUE BRIDGE TO SPUYTEN DUYVIL, JULY 15, 1913

High water occurred at Governors Island at 6.20 A. M. Low water at 12.45 P. M. There was no wind.

	A. M.									
985	10.40	Willis Ave. Bridge, Manhattan shore..	40 48 12	73 55 47	1	Ebb	21.1	28	1.30	23
986	10.45	Willis Ave. Bridge, Manhattan shore..	40 48 12	73 55 47	12	Ebb	21.7	25	1.40	25
987	10.55	Willis Ave. Bridge, Manhattan shore..	40 48 12	73 55 47	20	Ebb	21.4	25	1.40	25
988	11.00	Willis Ave. Bridge, Bronx shore.......	40 48 12	73 55 47	1	Ebb	21.7	23	1.03	19
989	11.03	Willis Ave. Bridge, Bronx shore.......	40 48 12	73 55 47	12	Ebb	21.1	23	1.17	21
990	11.08	Willis Ave. Bridge, Bronx shore......	40 48 12	73 55 47	20	Ebb	21.1	23	2.24	41
991	11.20	3d Avenue Bridge, midstream........	40 48 25	73 55 58	1	Ebb	21.1	28	1.93	35
992	11.25	3d Avenue Bridge, midstream........	40 48 25	73 55 58	12	Ebb	20.6	28	1.89	33
993	11.28	3d Avenue Bridge, midstream........	40 48 25	73 55 58	20	Ebb	20.6	28	1.04	18
	P. M.									
994	12.35	207th Street Bridge, midstream.......	40 51 46	73 54 54	1	Ebb	21.7	33	1.20	21
995	12.38	207th Street Bridge, midstream.......	40 51 46	73 54 54	12	Ebb	21.7	33	1.20	21
996	12.40	207th Street Bridge, midstream.......	40 51 46	73 54 54	18	Ebb	21.7	33	1.20	21
997	12.54	Spuyten Duyvil, 50 feet off north shore	40 52 42	73 55 29	1	Ebb	22.6	36	0.75	14
998	12.57	Spuyten Duyvil, 50 feet off north shore	40 52 42	73 55 29	12	Ebb	22.2	36	0.27	5
999	1.00	Spuyten Duyvil, 50 feet off north shore	40 52 42	73 55 29	18	Ebb	22.2	39	1.21	21
1000	1.05	Spuyten Duyvil, 50 feet off north shore	40 52 41	73 55 29	1	Ebb	22.2	36	0.84	15
1001	1.08	Spuyten Duyvil, 50 feet off south shore	40 52 41	73 55 29	12	Ebb	22.2	39	1.05	19
1002	1.12	Spuyten Duyvil, 50 feet off south shore	40 52 41	73 55 29	18	Ebb	21.9	39	0.91	17

TABLE CXXV—Continued

24—HUDSON RIVER, CROSS-SECTION, MT. ST. VINCENT. JULY 16, 1913

High water occurred at Governors Island at 7.15 A. M. Low water at 1.35 P. M. The wind was north, with a velocity of 5 to 40 miles per hour.

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1003	6.50	300 feet off dock at Mt. St. Vincent...	40 54 50	73 54 56	1	Flood	22.5	64	4.30	73
1004	6.55	300 feet off dock at Mt. St. Vincent...	40 54 50	73 54 56	18	Flood	22.2	64	4.80	82
1005	7.00	300 feet off dock at Mt. St. Vincent...	40 54 50	73 54 56	48	Flood	22.2	61	3.30	57
1006	7.10	¼ way across....................	40 54 50	73 54 59	1	Flood	22.2	67	3.99	67
1007	7.14	¼ way across....................	40 54 50	73 54 59	18	Flood	22.2	63	4.31	73
1008	7.18	¼ way across....................	40 54 50	73 54 59	48	Flood	22.2	59	4.65	80
1009	7.22	½ way across....................	40 54 50	73 55 15	1	Flood	22.2	67	3.57	60
1010	7.25	½ way across....................	40 54 50	73 55 15	18	Flood	22.2	64	4.26	72
1011	7.30	½ way across....................	40 54 50	73 55 15	48	Flood	22.2	56	4.95	87
1012	7.33	¾ way across....................	40 54 50	73 55 30	1	Flood	22.5	67	3.98	68
1013	7.36	¾ way across....................	40 54 50	73 55 30	18	Flood	22.2	63	4.65	79
1014	7.40	¾ way across....................	40 54 50	73 55 30	42	Flood	22.2	55	5.22	90
1015	7.45	300 feet off New Jersey shore.........	40 54 50	73 55 40	1	Ebb	22.5	64	4.99	85
1016	7.50	300 feet off New Jersey shore.........	40 54 50	73 55 40	18	Ebb	22.2	64	4.81	82
1017	8.00	300 feet off New Jersey shore.........	40 54 50	73 55 40	36	Ebb	22.2	64	4.41	75
1018	9.20	300 feet off Mt. St. Vincent..........	40 54 50	73 54 46	1	Ebb	22.5	61	3.90	65
1019	9.23	300 feet off Mt. St. Vincent..........	40 54 50	73 54 46	18	Ebb	22.5	61	4.20	70
1020	9.26	300 feet off Mt. St. Vincent..........	40 54 50	73 54 46	48	Ebb	22.5	54	3.10	54
1021	9.30	¼ way across....................	40 54 50	73 54 59	1	Ebb	22.8	62	4.09	70
1022	9.34	¼ way across....................	40 54 50	73 54 59	18	Ebb	22.5	61	4.11	71
1023	9.36	¼ way across....................	40 54 50	73 54 59	48	Ebb	22.5	53	4.15	73
1024	9.44	½ way across....................	40 54 50	73 55 15	1	Ebb	22.8	62	3.86	67
1025	9.48	½ way across....................	40 54 50	73 55 15	18	Ebb	22.5	62	3.76	65
1026	9.52	½ way across....................	40 54 50	73 55 15	48	Ebb	22.2	55	4.17	73
1027	9.55	¾ way across....................	40 54 50	73 55 30	1	Ebb	22.5	63	3.48	60
1028	10.00	¾ way across....................	40 54 50	73 55 30	18	Ebb	22.5	54	3.50	61
1029	10.05	¾ way across....................	40 54 50	73 55 30	48	Ebb	22.5	53	4.79	84
1030	10.10	300 feet off New Jersey shore.........	40 54 50	73 55 40	1	Ebb	23.1	62	4.78	83
1031	10.13	300 feet off New Jersey shore.........	40 54 50	73 55 40	18	Ebb	22.8	60	4.01	69
1032	10.17	300 feet off New Jersey shore.........	40 54 50	73 55 40	36	Ebb	22.8	58	4.10	71
1033	11.45	300 feet off dock at Mt. St. Vincent...	40 54 50	73 54 46	1	Ebb	23.9	59	4.98	88
1034	11.50	300 feet off dock at Mt. St. Vincent...	40 54 50	73 54 46	18	Ebb	23.3	59	4.60	81
1035	11.52	300 feet off dock at Mt. St. Vincent...	40 54 50	73 54 46	31	Ebb	22.8	56	3.00	53
1036	11.57	¼ way across....................	40 54 50	73 54 59	1	Ebb	23.0	59	3.98	70
1037	12.00	¼ way across....................	40 54 50	73 54 59	18	Ebb	22.8	60	4.20	73
1038	P. M. 12.03	¼ way across....................	40 54 50	73 54 59	42	Ebb	22.5	54	3.94	69
1039	12.08	½ way across....................	40 54 50	73 55 15	1	Ebb	22.8	62	3.96	70
1040	12.13	½ way across....................	40 54 50	73 55 15	18	Ebb	22.8	56	4.16	73
1041	12.16	½ way across....................	40 54 50	73 55 15	42	Ebb	22.8	54	4.76	86
1042	12.18	¾ way across....................	40 54 50	73 55 30	1	Ebb	23.6	59	4.12	73
1043	12.21	¾ way across....................	40 54 50	73 55 30	18	Ebb	23.0	56	4.09	72
1044	12.25	¾ way across....................	40 54 50	73 55 30	42	Ebb	23.0	56	5.12	90
1045	12.30	300 feet off New Jersey shore.........	40 54 50	73 55 40	1	Ebb	23.9	65	4.90	86
1046	12.35	300 feet off New Jersey shore.........	40 54 50	73 55 40	12	Ebb	23.3	64	4.70	81
1047	12.40	300 feet off New Jersey shore.........	40 54 50	73 55 40	30	Ebb	23.0	59	4.05	71
1048	1.55	300 feet off dock at Mt. St. Vincent...	40 54 50	73 54 46	1	Flood	23.9	63	4.37	77
1049	1.59	300 feet off dock at Mt. St. Vincent..	40 54 50	73 54 46	12	Flood	23.3	62	4.40	78
1050	2.01	300 feet off dock at Mt. St. Vincent...	40 54 50	73 54 46	36	Flood	23.3	58	4.30	76
1051	2.05	¼ way across....................	40 54 50	73 54 59	1	Flood	23.3	66	5.20	90

TABLE CXXV—Continued

24—HUDSON RIVER, CROSS-SECTION, MT. ST. VINCENT. JULY 16, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1052	2.10	¼ way across	40 54 50	73 54 59	18	Flood	23.1	60	4.41	77
1053	2.12	¼ way across	40 54 50	73 54 59	42	Flood	22.8	58	4.46	78
1054	2.17	½ way across	40 54 50	73 55 15	1	Flood	23.9	69	4.68	81
1055	2.20	½ way across	40 54 50	73 55 15	18	Flood	23.3	62	4.66	81
1056	2.25	½ way across	40 54 50	73 55 15	42	Flood	23.3	62	5.43	94
1057	2.30	¾ way across	40 54 50	73 55 30	1	Flood	24.1	69	4.76	83
1058	2.34	¾ way across	49 54 50	73 55 30	12	Flood	23.3	68	5.62	95
1059	2.38	¾ way across	40 54 50	73 55 30	24	Flood	23.1	63	5.76	98
1060	2.40	300 feet off New Jersey shore	40 54 50	73 55 40	1	Flood	23.9	69	5.79	102
1061	2.45	300 feet off New Jersey shore	40 54 50	73 55 40	12	Flood	23.0	70	5.90	102
1062	2.50	300 feet off New Jersey shore	40 54 50	73 55 40	24	Flood	23.3	70	6.06	103
1063	4.50	300 feet off dock at Mt. St. Vincent	40 54 50	73 54 46	1	Flood	24.5	68	6.07	108
1064	4.53	300 feet off dock at Mt. St. Vincent	40 54 50	73 54 46	18	Flood	23.6	63	4.60	80
1065	4.56	300 feet off dock at Mt. St. Vincent	40 54 50	73 54 46	30	Flood	23.9	55	4.30	76
1066	4.58	¼ way across	40 54 50	73 54 59	1	Flood	23.3	69	5.80	101
1067	5.01	¼ way across	40 54 50	73 54 59	18	Flood	23.1	64	5.32	93
1068	5.05	¼ way across	40 54 50	73 54 59	36	Flood	23.9	60	4.67	82
1069	5.08	½ way across	40 54 50	73 55 15	1	Flood	23.3	67	5.78	101
1070	5.11	½ way across	40 54 50	73 55 15	18	Flood	23.3	66	4.26	74
1071	5.15	½ way across	40 54 50	73 55 15	36	Flood	23.3	55	5.22	93
1072	5.20	¾ way across	40 54 50	73 55 30	1	Flood	23.9	73	5.95	103
1073	5.22	¾ way across	40 54 50	73 55 30	12	Flood	24.1	69	6.38	112
1074	5.26	¾ way across	40 54 50	73 55 30	24	Flood	23.3	62	6.06	106
1075	5.30	300 feet off New Jersey shore	40 54 50	73 55 40	1	Flood	23.9	69	6.40	112
1076	5.35	300 feet off New Jersey shore	40 54 50	73 55 40	12	Flood	23.9	71	6.00	104
1077	5.40	300 feet off New Jersey shore	40 54 50	73 55 40	18	Flood	23.3	78	6.42	109

25—HUDSON RIVER, YONKERS TO PIER A. JULY 17, 1913

High water occurred at Governors Island at 7.50 A. M. Low water at 2.10 P. M. The wind was light, and varied from north to south.

	A. M.									
1078	6.55	Midstream, opposite Power House above Yonkers	40 56 55	73 54 35	1	Flood	22.8	70	5.58	95
1079	6.58	Midstream, opposite Power House above Yonkers	40 56 55	73 54 35	18	Flood	23.1	64	3.90	68
1080	7.00	Midstream, opposite Power House above Yonkers	40 56 55	73 54 35	42	Flood	22.8	60	4.70	81
1081	7.20	Midstream, opposite Mt. St. Vincent	40 54 50	73 55 15	1	Flood	22.8	68	5.58	95
1082	7.25	Midstream, opposite Mt. St. Vincent	40 54 50	73 55 15	18	Flood	23.1	62	4.50	79
1083	7.35	Midstream, opposite Mt. St. Vincent	40 54 50	73 55 15	42	Flood	22.8	56	4.40	77
1084	7.45	Midstream, opposite Riverdale	40 54 10	73 55 25	1	Flood	22.8	64	5.58	95
1085	7.50	Midstream, opposite Riverdale	40 54 10	73 55 25	12	Flood	22.8	52	3.80	67
1086	7.55	Midstream, opposite Riverdale	40 54 10	73 55 25	24	Flood	22.8	52	2.90	51
1087	8.15	Midstream, opposite Spuyten Duyvil	40 52 50	73 56 04	1	Ebb	22.8	58	4.18	71
1088	8.20	Midstream, opposite Spuyten Duyvil	40 52 50	73 56 04	12	Ebb	22.8	54	3.90	68
1089	8.25	Midstream, opposite Spuyten Duyvil	40 52 50	73 56 04	24	Ebb	22.2	57	2.90	50
1090	8.45	Midstream, opposite Inwood	40 52 20	73 56 24	1	Ebb	23.1	56	4.48	79
1091	8.50	Midstream, opposite Inwood	40 52 20	73 56 24	12	Ebb	22.5	51	2.80	49
1092	8.55	Midstream, opposite Inwood	40 52 20	73 56 24	30	Ebb	22.2	49	2.90	51
1093	9.20	Mid-channel, opposite Ft. Washington Point	40 51 04	73 57 13	1	Ebb	22.2	49	4.08	72

TABLE CXXV—Continued

25—HUDSON RIVER, YONKERS TO PIER A. JULY 17, 1913—Continued

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1094	9.30	Mid-channel, opposite Ft. Washington Point	40 51 04	73 57 13	18	Ebb	22.1	47	3.30	58
1095	9.35	Mid-channel, opposite Ft. Washington Point	40 51 04	73 57 13	48	Ebb	21.7	44	2.00	35
1096	9.55	Mid-channel, opposite 129th street	40 49 16	73 58 10	1	Ebb	22.8	42	3.69	67
1097	10.06	Mid-channel, opposite 129th street	40 49 16	73 58 10	18	Ebb	22.2	41	2.60	46
1098	10.10	Mid-channel, opposite 129th street	40 49 16	73 58 10	48	Ebb	21.7	35	3.50	63
1099	10.30	Mid-channel, opposite W. 110th street	40 48 32	73 58 40	1	Ebb	22.2	37	3.28	59
1100	10.35	Mid-channel, opposite W. 110th street	40 48 32	73 58 40	18	Ebb	22.0	37	3.20	57
1101	10.40	Mid-channel, opposite W. 110th street	40 48 32	73 58 40	48	Ebb	21.7	35	3.30	59
1102	10.55	Mid-channel, opposite W. 72d street	40 47 02	73 69 42	1	Ebb	22.2	35	3.59	65
1103	11.00	Mid-channel, opposite W. 72d street	40 47 02	73 69 42	18	Ebb	21.7	35	3.30	59
1104	11.05	Mid-channel, opposite W. 72d street	40 47 02	73 69 42	48	Ebb	21.4	33	2.50	45
1105	11.25	Mid-channel, opposite W. 42d street	40 45 50	74 00 35	1	Ebb	21.7	33	3.09	55
1106	11.28	Mid-channel, opposite W. 42d street	40 45 50	74 00 35	18	Ebb	21.7	33	2.50	45
1107	11.30	Mid-channel, opposite W. 42d street	40 45 50	74 00 35	48	Ebb	21.1	30	3.80	68
1108	11.45	Mid-channel, off 23d street	40 45 09	74 01 00	1	Ebb	22.0	33	3.59	63
1109	11.50	Mid-channel, off 23d street	40 45 09	74 01 00	18	Ebb	21.7	33	3.30	59
1110	11.55	Mid-channel, off 23d street	40 45 09	74 01 00	30	Ebb	21.1	30	3.60	64
	P. M.									
1111	12.15	Mid-channel, off Canal street	40 43 38	74 01 17	1	Ebb	21.7	31	3.99	70
1112	12.20	Mid-channel, off Canal street	40 43 38	74 01 17	18	Ebb	21.1	28	3.10	55
1113	12.25	Mid-channel, off Canal street	40 43 38	74 01 17	42	Ebb	20.3	26	3.40	61
1114	12.40	Mid-channel, off Pier A	40 42 19	74 01 34	1	Ebb	21.9	28	3.68	67
1115	12.45	Mid-channel, off Pier A	40 42 19	74 01 34	18	Ebb	21.1	27	3.30	59
1116	12.50	Mid-channel, off Pier A	40 42 19	74 01 34	36	Ebb	20.6	26	2.90	52

26—EAST RIVER, CROSS SECTION, PIER 10, MANHATTAN, TO PIER 10, BROOKLYN, JULY 18, 1913

High water occurred at Governors Island at 8.10 A. M. Low water at 2.50 P. M. The wind was light and variable.

	A. M.								
1117	7.25	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	1	Flood	20.0	25	3.39	60
1118	7.28	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	15	Flood	20.3	24	2.90	52
1119	7.32	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	30	Flood	20.3	24	2.80	50
1120	7.38	¼ way across	40 42 07	74 00 17	1	Flood	20.3	26	2.56	46
1121	7.41	¼ way across	40 42 07	74 00 17	15	Flood	20.3	26	2.99	53
1122	7.46	¼ way across	40 42 07	74 00 17	40	Flood	20.0	25	2.27	40
1123	7.50	½ way across	40 42 03	74 00 11	1	Flood	20.0	25	2.40	42
1124	7.55	½ way across	40 42 03	74 00 11	15	Flood	20.0	25	3.05	54
1125	8.00	½ way across	40 42 03	74 00 11	40	Flood	20.0	23	3.71	66
1126	8.05	¾ way across	40 42 00	74 00 05	1	Flood	20.0	27	2.66	47
1127	8.09	¾ way across	40 42 00	74 00 05	15	Flood	20.0	27	2.92	51
1128	8.11	¾ way across	40 42 00	74 00 05	35	Flood	20.0	27	4.32	76
1129	8.15	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Flood	20.0	25	3.29	59
1130	8.20	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	15	Flood	20.0	23	3.20	57
1131	8.25	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	30	Flood	20.0	23	3.08	55
1132	9.30	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	1	Ebb	20.0	23	2.69	48
1133	9.35	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	15	Ebb	20.0	23	3.40	60
1134	9.40	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	30	Ebb	20.0	23	2.50	45
1135	9.42	¼ way across	40 42 07	74 00 17	1	Ebb	20.0	23	2.87	51
1136	9.46	¼ way across	40 42 07	74 00 17	15	Ebb	20.0	21	3.09	55
1137	9.49	¼ way across	40 42 07	74 00 17	40	Ebb	20.0	21	3.51	62

TABLE CXXV—Continued

26—EAST RIVER, CROSS SECTION, PIER 10, MANHATTAN, TO PIER 10, BROOKLYN. JULY 18, 1913—Continued

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1138	9.51	½ way across	40 42 03	74 00 11	1	Ebb	20.0	25	2.91	52
1139	9.54	½ way across	40 42 03	74 00 11	15	Ebb	20.0	25	3.45	61
1140	9.58	½ way across	40 42 03	74 00 11	40	Ebb	20.0	25	3.00	54
1141	10.00	¾ way across	40 42 00	74 00 05	1	Ebb	20.0	25	2.93	52
1142	10.05	¾ way across	40 42 00	74 00 05	15	Ebb	20.0	25	3.60	64
1143	10.10	¾ way across	40 42 00	74 00 05	35	Ebb	20.0	25	4.32	76
1144	10.40	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Ebb	20.0	23	2.88	51
1145	10.45	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	15	Ebb	20.0	23	2.92	52
1146	10.50	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	30	Ebb	20.0	23	2.38	42
1147	11.45	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	1	Ebb	21.1	24	2.60	47
1148	11.47	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	15	Ebb	21.1	24	2.60	47
1149	11.50	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	30	Ebb	20.6	24	2.50	45
1150	11.55	¼ way across	40 42 07	74 00 17	1	Ebb	20.6	22	1.96	35
1151	11.58	¼ way across	40 42 07	74 00 17	15	Ebb	20.6	22	2.38	43
	P. M.									
1152	12.01	¼ way across	40 42 07	74 00 17	40	Ebb	20.6	22	2.55	46
1153	12.05	½ way across	40 42 03	74 00 11	1	Ebb	20.6	24	1.99	35
1154	12.10	½ way across	40 42 03	74 00 11	15	Ebb	20.6	24	2.45	44
1155	12.14	½ way across	40 42 03	74 00 11	40	Ebb	20.8	24	2.78	50
1156	12.17	¾ way across	40 42 00	74 00 05	1	Ebb	20.8	28	2.26	40
1157	12.20	¾ way across	40 42 00	74 00 05	15	Ebb	20.8	24	2.19	37
1158	12.25	¾ way across	40 42 00	74 00 05	35	Ebb	20.6	24	3.18	57
1159	12.30	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Ebb	20.8	24	2.37	42
1160	12.33	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	15	Ebb	20.8	24	2.11	38
1161	12.35	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	30	Ebb	20.8	24	1.88	33
1162	1.37	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	1	Ebb	21.1	24	2.49	45
1163	1.40	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	15	Ebb	21.1	24	2.20	40
1164	1.45	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	30	Ebb	21.1	24	1.80	32
1165	1.47	¼ way across	40 42 07	74 00 17	1	Ebb	21.1	24	1.56	28
1166	1.49	¼ way across	40 42 07	74 00 17	15	Ebb	21.1	24	1.88	34
1167	1.55	¼ way across	40 42 07	74 00 17	40	Ebb	21.1	24	2.36	43
1168	2.00	½ way across	40 42 03	74 00 11	1	Ebb	21.1	24	1.48	27
1169	2.05	½ way across	40 42 03	74 00 11	15	Ebb	21.1	24	1.85	32
1170	2.08	½ way across	40 42 03	74 00 11	40	Ebb	21.1	24	1.12	20
1171	2.10	¾ way across	40 42 00	74 00 05	1	Ebb	21.1	24	1.56	28
1172	2.15	¾ way across	40 42 00	74 00 05	15	Ebb	21.1	24	1.88	34
1173	2.20	¾ way across	40 42 00	74 00 05	35	Ebb	21.1	24	2.80	50
1174	2.25	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Flood	21.1	24	2.17	39
1175	2.27	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	15	Flood	21.1	24	2.01	36
1176	2.30	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	30	Flood	21.1	24	1.78	32
1177	3.40	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	1	Flood	21.7	23	2.69	49
1178	3.43	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	15	Flood	21.1	24	1.80	33
1179	3.45	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	30	Flood	21.1	22	1.90	35
1180	3.50	¼ way across	40 42 07	74 00 17	1	Flood	21.1	24	1.67	30
1181	3.54	¼ way across	40 42 07	74 00 17	15	Flood	20.8	24	1.48	26
1182	3.56	¼ way across	40 42 07	74 00 17	40	Flood	20.8	24	2.26	40
1183	4.00	½ way across	40 42 03	74 00 11	1	Flood	21.1	26	0.87	15
1184	4.04	½ way across	40 42 03	74 00 11	15	Flood	21.1	26	1.36	24
1185	4.08	½ way across	40 42 03	74 00 11	40	Flood	21.1	26	2.06	37
1186	4.10	¾ way across	40 42 00	74 00 05	1	Flood	21.1	24	1.94	35
1187	4.12	¾ way across	40 42 00	74 00 05	15	Flood	21.1	24	2.74	51
1188	4.15	¾ way across	40 42 00	74 00 05	35	Flood	20.8	22	3.17	57

TABLE CXXV—Continued

26—EAST RIVER, CROSS SECTION, PIER 10, MANHATTAN, TO PIER 10, BROOKLYN, JULY 18, 1913—Continued

Sample No.	Hour P. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1189	4.20	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Flood	21.1	24	1.76	32
1190	4.25	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	15	Flood	21.1	24	2.11	38
1191	4.30	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	30	Flood	20.8	24	1.58	28
1192	6.05	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	1	Flood	22.2	31	1.77	32
1193	6.09	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	15	Flood	21.4	23	1.20	22
1194	6.12	100 feet off Pier 10, Manhattan	40 42 09	74 00 22	30	Flood	20.8	24	1.20	22
1195	6.15	¼ way across	40 42 07	74 00 17	1	Flood	21.1	26	1.36	24
1196	6.18	¼ way across	40 42 07	74 00 17	15	Flood	21.1	26	1.08	19
1197	6.20	¼ way across	40 42 07	74 00 17	40	Flood	20.6	28	1.58	28
1198	6.25	½ way across	40 42 03	74 00 11	1	Flood	21.1	28	0.71	13
1199	6.28	½ way across	40 42 03	74 00 11	15	Flood	21.1	28	1.36	24
1200	6.30	½ way across	40 42 03	74 00 11	40	Flood	20.8	26	1.26	22
1201	6.34	¾ way across	40 42 00	74 00 05	1	Flood	21.1	32	0.92	16
1202	6.36	¾ way across	40 42 00	74 00 05	15	Flood	21.1	30	1.55	28
1203	6.39	¾ way across	40 42 00	74 00 05	35	Flood	21.1	28	2.44	44
1204	6.40	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	1	Flood	21.4	31	1.75	31
1205	6.45	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	15	Flood	21.1	28	2.10	38
1206	6.50	100 feet off Pier 10, Brooklyn	40 41 57	74 00 00	30	Flood	20.8	28	1.59	28

27—NARROWS, CROSS-SECTION, FORT LAFAYETTE TO FORT WADSWORTH. JULY 24, 1913

Low water occurred at Governors Island at 6.10 A. M. High water at 1.00 P. M. The wind was southeast, with a velocity of 5 miles per hour.

	A. M.									
1207	7.30	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Flood	21.1	20	3.20	58
1208	7.33	200 feet off Fort Lafayette	40 36 29	74 02 24	18	Flood	21.1	22	3.40	62
1209	7.38	200 feet off Fort Lafayette	40 36 29	74 02 24	54	Flood	20.6	18	4.26	77
1210	7.40	¼ way across	40 36 27	74 02 34	1	Flood	21.1	24	2.70	49
1211	7.43	¼ way across	40 36 27	74 02 34	24	Flood	21.1	20	2.73	50
1212	7.45	¼ way across	40 36 27	74 02 34	54	Flood	20.6	20	4.32	78
1213	7.50	½ way across	40 36 25	74 02 48	1	Flood	21.1	24	3.01	55
1214	7.53	½ way across	40 36 25	74 02 48	30	Flood	20.6	20	4.49	81
1215	7.57	½ way across	40 36 25	74 02 48	54	Flood	20.6	16	3.98	72
1216	8.03	¾ way across	40 36 23	74 03 02	1	Flood	21.1	24	3.22	58
1217	8.06	¾ way across	40 36 23	74 03 02	30	Flood	20.9	20	3.03	54
1218	8.10	¾ way across	40 36 23	74 03 02	54	Flood	20.6	16	4.16	76
1219	8.15	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Flood	21.1	24	2.92	56
1220	8.18	200 feet off Fort Wadsworth	40 36 21	74 03 12	30	Flood	20.9	20	4.30	77
1221	8.25	200 feet off Fort Wadsworth	40 36 21	74 03 12	60	Flood	20.6	18	3.94	72
1222	9.35	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Flood	22.2	19	3.30	66
1223	9.38	200 feet off Fort Lafayette	40 36 29	74 02 24	30	Flood	21.1	18	3.90	71
1224	9.40	200 feet off Fort Lafayette	40 36 29	74 02 24	45	Flood	20.6	16	4.15	75
1225	9.45	¼ way across	40 36 27	74 02 34	1	Flood	21.4	21	3.38	62
1226	9.48	¼ way across	40 36 27	74 02 34	30	Flood	20.8	20	3.84	70
1227	9.52	¼ way across	40 36 27	74 02 34	60	Flood	20.6	18	4.24	76
1228	9.55	½ way across	40 36 25	74 02 48	1	Flood	21.1	21	3.88	70
1229	9.58	½ way across	40 36 25	74 02 48	30	Flood	20.8	18	4.38	80
1230	10.00	½ way across	40 36 25	74 02 48	60	Flood	20.6	18	4.29	76
1231	10.05	¾ way across	40 36 23	74 03 02	1	Flood	21.1	20	4.38	80
1232	10.10	¾ way across	40 36 23	74 03 02	30	Flood	20.8	20	3.33	60
1233	10.12	¾ way across	40 36 23	74 03 02	60	Flood	20.6	18	3.76	68

TABLE CXXV—Continued

27—NARROWS, CROSS-SECTION, FORT LAFAYETTE TO FORT WADSWORTH. JULY 24 1913—Continued

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1234	10.18	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Flood	21.1	22	3.43	63
1235	10.20	200 feet off Fort Wadsworth	40 36 21	74 03 12	18	Flood	21.1	16	4.30	79
1236	10.25	200 feet off Fort Wadsworth	40 36 21	74 03 12	40	Flood	20.8	20	3.74	68
1237	11.50	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Ebb	21.4	19	3.20	59
1238	11.53	200 feet off Fort Lafayette	40 36 29	74 02 24	30	Ebb	20.8	16	4.10	75
1239	11.58	200 feet off Fort Lafayette	40 36 29	74 02 24	54	Ebb	20.8	16	4.35	80
1240	12.00	¼ way across	40 36 27	74 02 34	1	Ebb	21.1	19	4.38	80
1241	P. M. 12.03	¼ way across	40 36 27	74 02 34	30	Ebb	21.1	19	4.14	76
1242	12.05	¼ way across	40 36 27	74 02 34	60	Ebb	20.8	18	4.64	85
1243	12.08	½ way across	40 36 25	74 02 48	1	Ebb	21.7	21	4.57	84
1244	12.15	½ way across	40 36 25	74 02 48	30	Ebb	21.1	19	5.33	98
1245	12.20	½ way across	40 36 25	74 02 48	60	Ebb	21.1	18	5.19	95
1246	12.25	¾ way across	40 36 23	74 03 02	1	Ebb	21.1	21	4.19	77
1247	12.29	¾ way across	40 36 23	74 03 02	30	Ebb	21.1	19	4.68	86
1248	12.32	¾ way across	40 36 23	74 03 02	60	Ebb	21.1	19	4.86	89
1249	12.35	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Ebb	20.6	22	3.94	71
1250	12.40	200 feet off Fort Wadsworth	40 36 21	74 03 12	18	Ebb	20.6	20	4.68	86
1251	12.45	200 feet off Fort Wadsworth	40 36 21	74 03 12	40	Ebb	20.6	20	4.96	90
1252	2.55	200 feet off Fort Lafayette	40 36 29	74 02 24	1	Ebb	21.1	24	4.40	80
1253	3.00	200 feet off Fort Lafayette	40 36 29	74 02 24	30	Ebb	20.8	18	4.60	84
1254	3.05	200 feet off Fort Lafayette	40 36 29	74 02 24	54	Ebb	20.6	18	4.95	90
1255	3.07	¼ way across	40 36 27	74 02 34	1	Ebb	21.1	20	4.79	88
1256	3.12	¼ way across	40 36 27	74 02 34	30	Ebb	20.8	16	4.75	87
1257	3.16	¼ way across	40 36 27	74 02 34	60	Ebb	20.6	16	4.84	89
1258	3.18	½ way across	40 36 25	74 02 48	1	Ebb	21.1	20	4.84	89
1259	3.21	½ way across	40 36 25	74 02 48	30	Ebb	20.8	18	5.23	95
1260	3.25	½ way across	40 36 25	74 02 48	60	Ebb	20.6	18	5.10	91
1261	3.30	¾ way across	40 36 23	74 03 02	1	Ebb	21.4	21	5.15	95
1262	3.35	¾ way across	40 36 23	74 03 02	30	Ebb	20.8	18	3.85	70
1263	3.40	¾ way across	40 36 23	74 03 02	60	Ebb	20.6	16	4.86	89
1264	3.45	200 feet off Fort Wadsworth	40 36 21	74 03 12	1	Ebb	21.1	26	4.14	75
1265	3.50	200 feet off Fort Wadsworth	40 36 21	74 03 12	18	Ebb	20.6	20	4.69	86
1266	3.55	200 feet off Fort Wadsworth	40 36 21	74 03 12	40	Ebb	20.6	18	4.55	83

28—EAST RIVER TO NARROWS, MIDSTREAM. JULY 25, 1913

Low water occurred at Governors Island at 7.00 A. M. High water at 1.45 P. M. The wind was northwest, with a velocity of 5 to 10 miles per hour.

1267	A. M. 7.00	East river, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	21.7	25	1.20	22
1268	7.05	East river, at Brooklyn Bridge	40 42 20	73 59 48	15	Flood	21.1	25	1.10	20
1269	7.10	East river, at Brooklyn Bridge	40 42 20	73 59 48	36	Flood	21.1	28	1.35	24
1270	7.28	Hudson river, at Pier A	40 42 19	74 01 34	1	Flood	21.1	36	2.70	48
1271	7.33	Hudson river, at Pier A	40 42 19	74 01 34	18	Flood	21.1	34	2.03	36
1272	7.37	Hudson river, at Pier A	40 42 19	74 01 34	36	Flood	21.1	32	2.54	45
1273	8.05	Robbins Reef, at bell buoy	40 39 15	74 03 50	1	Flood	21.1	28	2.10	38
1274	8.10	Robbins Reef, at bell buoy	40 39 15	74 03 50	30	Flood	20.8	26	2.40	43
1275	8.15	Robbins Reef, at bell buoy	40 39 15	74 03 50	45	Flood	20.8	26	2.86	51
1276	8.40	Kill van Kull, at Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	21.9	27	3.60	66
1277	8.45	Kill van Kull, at Sailors Snug Harbor	40 38 50	74 06 25	15	Flood	21.7	27	3.10	57
1278	8.50	Kill van Kull, at Sailors Snug Harbor	40 38 50	74 06 25	25	Flood	21.7	27	3.25	59

TABLE CXXV—Continued

28—EAST RIVER TO NARROWS, MIDSTREAM. JULY 25, 1913—Continued

Sample No.	Hour A. M.	Location of Samples: Approximate	Location of Samples: Latitude	Location of Samples: Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen: C. C. per litre	Oxygen: Per cent saturation
			° ′ ″	° ′ ″						
1279	9.30	Narrows, between forts	40 36 25	74 02 48	1	Flood	21.7	25	3.10	57
1280	9.37	Narrows, between forts	40 36 25	74 02 48	30	Flood	21.1	20	3.40	62
1281	9.40	Narrows, between forts	40 36 25	74 02 48	60	Flood	20.8	18	4.05	74
	P. M.									
1282	12.25	East river, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	22.2	29	2.60	47
1283	12.30	East river, at Brooklyn Bridge	40 42 20	73 59 48	15	Ebb	21.9	27	2.40	44
1284	12.35	East river, at Brooklyn Bridge	40 42 20	73 59 48	36	Ebb	21.7	28	2.45	44
1285	12.55	Hudson river, at Pier A	40 42 19	74 01 34	1	Ebb	22.8	30	2.88	53
1286	1.00	Hudson river, at Pier A	40 42 19	74 01 34	18	Ebb	22.2	29	2.53	50
1287	1.05	Hudson river, at Pier A	40 42 19	74 01 34	36	Ebb	21.7	29	2.51	45
1288	1.40	Robbins Reef, at bell buoy	40 39 15	74 03 50	1	Ebb	21.7	17	3.80	70
1289	1.45	Robbins Reef, at bell buoy	40 39 15	74 03 50	30	Ebb	21.1	18	3.80	70
1290	1.50	Robbins Reef, at bell buoy	40 39 15	74 03 50	45	Ebb	20.6	16	4.35	80
1291	2.10	Kill van Kull, at Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	22.2	27	2.80	51
1292	2.15	Kill van Kull, at Sailors Snug Harbor	40 38 50	74 06 25	15	Ebb	22.0	26	3.30	60
1293	2.20	Kill van Kull, at Sailors Snug Harbor	40 38 50	74 06 25	25	Ebb	21.1	20	3.65	67
1294	3.00	Narrows, between forts	40 36 25	74 02 48	1	Ebb	21.1	20	4.10	75
1295	3.15	Narrows, between forts	40 36 25	74 02 48	30	Ebb	21.1	18	4.30	79
1296	3.25	Narrows, between forts	40 36 25	74 02 48	60	Ebb	21.1	18	5.25	96

29—HARLEM RIVER, BACK OF WARDS ISLAND. AUGUST 14, 1913

High water occurred at Governors Island at 6.50 A. M. The wind was south, with a velocity of 5 miles per hour.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen: C. C. per litre	Oxygen: Per cent saturation
	P. M.									
1297	12.35	Midstream	40 47 23	73 56 07	24	Ebb	23.3	20	2.60	49
1298	12.50	Midstream	40 47 23	73 56 07	2	Ebb	23.9	23	1.40	26

30—EAST RIVER, PIER 10. AUGUST 15, 1913

High water occurred at Governors Island at 7.45 A. M. Low water at 1.45 P. M. The wind was south, with a velocity of 3 miles per hour.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen: C. C. per litre	Oxygen: Per cent saturation
	A. M.									
1299	11.45	Midstream	40 42 03	74 00 11	20	Ebb	23.9	23	2.05	39

31—EAST RIVER. AUGUST 21, 1913

High water occurred at Governors Island at 10.55 P. M. The wind was southeast, with a velocity of 10 miles per hour.

Sample No.	Hour	Approximate	Latitude	Longitude	Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen: C. C. per litre	Oxygen: Per cent saturation
	A. M.									
1302	11.15	East river, at Mill Rock	40 46 50	73 56 25	24	Flood	21.7	21	2.88	53
1303	11.45	Midstream, at Queensboro Bridge	40 45 25	73 57 55	24	Flood	23.9	20	3.38	65
	P. M.									
1304	12.10	Midstream, at Williamsburgh Bridge	40 42 49	73 58 21	24	Flood	23.3	20	2.08	39
1305	12.35	Midstream, at Brooklyn Bridge	40 42 20	73 59 48	24	Ebb	23.3	20	2.18	41

TABLE CXXV—Continued

32—EAST RIVER, HUDSON RIVER, ROBBINS REEF, KILL VAN KULL AND NARROWS. AUGUST 27, 1913

Low water occurred at Governors Island at 10.00 A. M. High water at 4.10 P. M. The wind was south, with a velocity of 3 to 10 miles per hour.

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1306	9.00	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	23.6	21	0.90	17
1307	9.10	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	18	Ebb	23.6	21	1.15	22
1308	9.20	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Ebb	23.6	21	1.34	25
1309	9.35	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Ebb	23.3	26	3.04	57
1310	9.45	Hudson river, midstream, off Pier A	40 42 19	74 01 34	18	Ebb	23.3	28	2.68	49
1311	9.55	Hudson river, midstream, off Pier A	40 42 19	74 01 34	36	Ebb	23.3	26	3.09	58
1312	10.25	Robbins Reef, near bell buoy	40 29 10	74 03 50	1	Flood	23.3	21	2.90	55
1313	10.30	Robbins Reef, near bell buoy	40 29 10	74 03 50	24	Flood	23.3	21	2.86	54
1314	10.50	Robbins Reef, near bell buoy	40 29 10	74 03 50	48	Flood	23.8	24	2.90	54
1315	11.10	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	1	Flood	23.3	23	4.30	81
1316	11.15	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	15	Flood	23.3	23	3.66	69
1317	11.25	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	30	Flood	23.3	23	3.40	64
1318	12.00	Narrows, midway, between forts	40 36 25	74 02 48	1	Flood	23.3	22	2.90	55
	P. M.									
1319	12.10	Narrows, midway, between forts	40 36 25	74 02 48	36	Flood	22.8	18	3.64	66
1320	12.15	Narrows, midway, between forts	40 36 25	74 02 48	54	Flood	22.8	18	4.30	79
1321	2.15	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	23.3	26	2.00	38
1322	2.20	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	18	Flood	23.3	26	1.96	36
1323	2.30	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	30	Flood	23.3	26	2.40	45
1324	2.50	Hudson river, midstream, off Pier A	40 42 19	74 01 34	1	Flood	23.3	26	2.40	45
1325	2.55	Hudson river, midstream, off Pier A	40 42 19	74 01 34	18	Flood	23.3	24	3.16	59
1326	3.00	Hudson river, midstream, off Pier A	40 42 19	74 01 34	36	Flood	23.3	24	2.70	51
1327	3.45	Robbins Reef, near bell buoy	40 39 10	74 03 50	1	Ebb	22.8	18	3.30	62
1328	3.55	Robbins Reef, near bell buoy	40 39 10	74 03 50	24	Ebb	22.8	16	3.27	62
1329	4.05	Robbins Reef, near bell buoy	40 39 10	74 03 50	48	Ebb	22.8	14	4.10	79
1330	4.30	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	23.3	20	3.30	63
1331	4.35	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	15	Ebb	23.0	20	3.26	61
1332	4.40	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	30	Ebb	22.8	18	3.50	66
1333	5.40	Narrows, midway between forts	40 36 25	74 02 48	1	Ebb	22.8	16	4.60	87
1334	5.45	Narrows, midway between forts	40 36 25	74 02 48	36	Ebb	22.6	16	4.87	92
1335	5.50	Narrows, midway between forts	40 36 25	74 02 48	54	Ebb	22.2	16	5.20	99

33—EAST RIVER, HUDSON RIVER, ROBBINS REEF, KILL VAN KULL AND NARROWS. SEPTEMBER 19, 1913.

High water occurred at Governors Island at 10.40 A. M. Low water at 4.30 P. M. The wind was northeast, with a velocity of 5 miles per hour.

	A. M.									
1339	9.05	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Flood	20.0	25	2.30	41
1340	9.15	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	18	Flood	20.0	25	2.20	39

TABLE CXXV—Continued

33—EAST RIVER, HUDSON RIVER, ROBBINS REEF, KILL VAN KULL AND NARROWS.
SEPTEMBER 19, 1913—Continued

Sample No.	Hour A. M.	Location of Samples			Feet below surface	Tidal current	Temp. water Deg. C.	Per cent. land water	Oxygen	
		Approximate	Latitude	Longitude					C. C. per litre	Per cent. saturation
			° ′ ″	° ′ ″						
1341	9.20	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	36	Flood	20.0	25	1.90	33
1342	9.50	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	1	Flood	19.7	25	2.70	49
1343	10.00	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	18	Flood	19.7	25	2.30	40
1344	10.05	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	36	Flood	19.5	25	2.80	50
1345	10.45	Robbins Reef, at bell buoy	40 39 15	74 03 50	1	Ebb	19.1	18	4.00	71
1346	10.50	Robbins Reef, at bell buoy	40 39 15	74 03 50	30	Ebb	19.1	18	4.20	74
1347	11.00	Robbins Reef, at bell buoy	40 39 15	74 03 50	48	Ebb	18.9	18	4.18	73
1348	11.30	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	19.4	23	2.70	47
1349	11.35	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	18	Ebb	19.4	21	3.20	56
1350	11.40	Kill van Kull, midstream, off Sailors Snug Harbor	40 38 50	74 06 25	36	Ebb	19.4	21	3.12	55
	P. M.									
1351	12.15	Narrows, midstream, between forts	40 36 25	74 02 48	1	Ebb	19.0	16	4.60	82
1352	12.25	Narrows, midstream, between forts	40 36 25	74 02 48	36	Ebb	19.0	13	4.90	88
1353	12.30	Narrows, midstream, between forts	40 36 25	74 02 48	54	Ebb	19.0	13	5.12	90
1354	1.40	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	1	Ebb	19.4	21	2.00	35
1355	1.45	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	18	Ebb	19.7	25	2.00	35
1356	1.55	East river, midstream, at Brooklyn Bridge	40 42 20	73 59 48	36	Ebb	19.7	25	1.99	35
1357	2.15	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	1	Ebb	19.4	23	3.20	57
1358	2.20	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	18	Ebb	19.2	23	3.40	60
1359	2.30	Hudson river, midstream, opposite Pier A	40 42 19	74 01 34	36	Ebb	19.2	21	3.51	62
1360	2.55	Robbins Reef, near bell buoy	40 39 15	74 03 50	1	Ebb	19.2	17	3.60	64
1361	3.00	Robbins Reef, near bell buoy	40 39 15	74 03 50	30	Ebb	18.9	17	3.70	66
1362	3.10	Robbins Reef, near bell buoy	40 39 15	74 03 50	48	Ebb	19.2	17	4.10	73
1363	3.35	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	1	Ebb	19.2	27	3.10	54
1364	3.45	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	18	Ebb	19.4	27	3.30	58
1365	3.50	Kill van Kull, midstream, opposite Sailors Snug Harbor	40 38 50	74 06 25	36	Ebb	19.4	27	3.50	61
1366	4.25	Narrows, midstream, between forts	40 36 25	74 02 48	1	Flood	19.2	21	3.40	60
1367	4.30	Narrows, midstream, between forts	40 36 25	74 02 48	36	Flood	19.2	17	3.60	64
1368	4.35	Narrows, midstream, between forts	40 36 25	74 02 48	54	Flood	19.2	21	3.60	60

TABLE CXXVI

Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1913
Averages for various parts of the harbor

Data for this table are contained in Table CXXV.

Location	Number of analyses	Averages: C. C. per litre	Averages: per cent. saturation	Samples included in the averages
Upper bay	65	4.21	70	317–318, 327–328, 337–338, 347–348, 391–393, 406–408, 418–420, 433–435, 796–822, 1273–1275, 1288–1290, 1312–1314, 1327–1329, 1345–1347, 1360–1362.
Hudson river, below Spuyten Duyvil	171	3.33	54	315–316, 325–326, 335–336, 349–350, 354, 366–371, 379–384, 394–396, 409–411, 415–417, 430–432, 706–795, 1087–1116, 1270–1272, 1285–1287, 1309–1311, 1324–1326, 1342–1344, 1357–1359.
Hudson river, above Spuyten Duyvil	84	4.65	81	1003–1086.
East river, below Hell Gate	260	2.53	43	313–314, 323–324, 333–334, 351–352, 355, 358–365, 377–378, 397–399, 412–414, 427–429, 443–537, 613–636, 1117–1206, 1267–1269, 1282–1284, 1299, 1302–1308, 1321–1323, 1339–1341, 1354–1356, (442 too near sewer, not included).
East river, above Hell Gate	153	3.80	67	643–705, 895–984.
Harlem river	27	1.70	29	353, 637–642, 985–1002, 1297–1298.
Kill van Kull	110	3.85	66	319–320, 329–330, 339–340, 345–346, 388–390, 403–405, 421–423, 436–438, 823–894, 1276–1278, 1291–1293, 1315–1317, 1330–1332, 1348–1350, 1363–1365.
The Narrows	173	4.10	73	321–322, 331–332, 341–344, 385–387, 400–402, 424–426, 439–441, 538–612, 1207–1266, 1279–1281, 1294–1296, 1318–1321, 1333–1335, 1351–1353, 1366–1368.
Gowanus canal	2	4.80	63	356–357.
Newtown creek	3	1.40	18	374–376.
Wallabout canal	2	4.68	61	372–373.

TABLE CXXVII

Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1913
Averages of samples taken at Surface, Mid-depth and Bottom for various parts of the harbor

Data for this table are contained in Table CXXV.

Location	Depths											
	Surface				Mid-depth				Bottom			
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Upper bay.........	23	4.09	66	317, 327, 337, 347, 391, 406, 418, 433, 796, 799, 802, 805, 808, 811, 814, 817, 820, 1273, 1288, 1312, 1327, 1345, 1360.	19	3.93	69	392, 407, 419, 434, 797, 800, 803, 806, 809, 812, 815, 818, 821, 1274, 1289, 1313, 1328, 1346, 1361.	23	4.57	74	318, 328, 338, 348, 393, 408, 420, 435, 798, 801, 804, 807, 810, 813, 816, 819, 822, 1275, 1290, 1314, 1329, 1347, 1362.
Hudson river, below Spuyten Duyvil..	63	3.56	57	315, 325, 335, 349, 354, 366–371, 379, 382, 394, 409, 415, 430, 706, 709, 712, 715, 718, 721, 724, 727, 730, 733, 736, 739, 742, 745, 748, 751, 754, 757, 760, 763, 766, 769, 772, 775, 778, 781, 784, 787, 790, 793, 1087, 1090, 1093, 1096, 1099, 1102, 1105, 1108, 1111. 1114, 1270, 1285, 1309, 1324, 1342, 1357.	52	3.10	53	380, 383, 395, 410, 416, 431, 707, 710, 713, 716, 719, 722, 725, 728, 731, 734, 737, 740, 743, 746, 749, 752, 755, 758, 761, 764, 767, 770, 773, 776, 779, 782, 785, 788, 791, 794, 1088, 1091, 1094, 1097, 1100, 1103, 1106, 1109, 1112, 1115, 1271, 1286, 1310, 1325. 1343, 1358.	56	3.27	54	316, 326, 336, 350, 381, 384, 396, 411, 417, 432, 708, 711, 714, 717, 720, 723, 726, 729, 732, 735, 738, 741, 744, 747, 750, 753, 756, 759, 762, 765. 768, 771, 774, 777, 780, 783, 786, 789, 792, 795, 1089, 1092, 1095, 1098, 1101, 1104, 1107, 1110, 1113, 1116, 1272, 1287, 1311, 1326, 1344, 1359.
Hudson river, above Spuyten Duyvil..	28	4.80	83	1003. 1006, 1009, 1012, 1015, 1018, 1021, 1024, 1027, 1030, 1033, 1036, 1039, 1042, 1045, 1048, 1051, 1054, 1057, 1060, 1063, 1066, 1069, 1072, 1075, 1078, 1081, 1084.	28	4.57	79	1004, 1007, 1010, 1013, 1016, 1019, 1022, 1025, 1028, 1031, 1034, 1037, 1040, 1043, 1046, 1049, 1052, 1055, 1058, 1061, 1064, 1067, 1070, 1073, 1076, 1079, 1082, 1085.	28	4.59	80	1005, 1008, 1011, 1014, 1017, 1020, 1023, 1026, 1029, 1032, 1035, 1038, 1041, 1044, 1047, 1050, 1053, 1056, 1059, 1062, 1065, 1068, 1071, 1074, 1077, 1080, 1083, 1086.
East river, below Hell Gate........	93	2.70	43	313, 323, 333, 351, 355, 358–365, 377–378, 397, 412, 427, 445, 448, 451, 454, 457, 460, 463, 466, 469, 472, 475, 478, 481, 484, 487, 490, 493, 496, 499, 502, 505, 508, 511, 514, 517, 520, 523, 526, 529, 532, 535, 613, 616, 619, 622, 625, 628, 631, 634, 1117, 1120, 1123, 1126, 1129, 1132, 1135, 1138, 1141, 1144, 1147, 1150, 1153, 1156,	84	2.26	40	398, 413, 428, 443, 446, 449, 452, 455, 458, 461, 464, 467, 470, 473, 476, 479, 482, 485, 488, 491, 494, 497, 500, 503, 506, 509, 512, 515, 518, 521, 524, 527, 530, 533, 536, 614, 617, 620, 623, 626, 629, 632, 635, 1118, 1121, 1124, 1127, 1130, 1133, 1136, 1139, 1142, 1145, 1148, 1151, 1154, 1157, 1160, 1163, 1166, 1169, 1172,	83	2.62	46	314, 324, 334, 352, 399, 414, 429, 444, 447, 450, 453, 456, 459, 462, 465, 468, 471, 474, 477, 480, 483, 486, 489, 492, 495, 498, 501, 504, 507, 510, 513, 516, 519, 522, 525, 528, 531, 534, 537, 615, 618, 621, 624, 627, 630, 633, 636, 1119, 1122, 1125, 1128, 1131, 1134, 1137, 1140, 1143, 1146, 1149, 1152, 1155, 1158, 1161, 1164,

TABLE CXXVII—Continued

Location	Depths											
	Surface				Mid-depth				Bottom			
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
East river, below Hell Gate—Cont.	93	2.70	43	1159, 1162, 1165, 1168, 1171, 1174, 1177, 1180, 1183, 1186, 1189, 1192, 1195, 1198, 1201, 1204, 1267, 1282, 1306, 1321, 1339, 1354.				1175, 1178, 1181, 1184, 1187, 1190, 1193, 1196, 1199, 1202, 1205, 1268, 1283, 1299, 1302, 1305, 1307, 1322, 1340, 1355.				1167, 1170, 1173, 1176, 1179, 1182, 1185, 1188, 1191, 1194, 1197, 1200, 1203, 1206, 1269, 1284, 1308, 1323, 1341, 1356.
East river, above Hell Gate........	51	3.64	64	643, 646, 649, 652, 655, 658, 661, 664, 667, 670, 673, 676, 679, 682, 685, 688, 691, 694, 697, 700, 703, 895, 898, 901, 904, 907, 910, 913, 916, 919, 922. 925, 928, 931, 934, 937, 940, 943, 946, 949, 952, 955, 958, 961, 964, 967, 970, 973, 976, 979, 982.	51	3.76	67	644, 647, 650, 653, 656, 659, 662, 665, 668, 671, 674, 677, 680, 683, 686, 689, 692, 695. 698, 701, 704, 896, 899, 902, 905, 908, 911, 914, 917, 920, 923, 926, 929, 932, 935, 938, 941, 944, 947, 950, 953, 956, 959, 962, 965, 968, 971, 974, 977, 980, 983.	51	3.98	70	645, 648, 651, 654, 657, 660, 663, 666, 669, 672, 675, 678, 681, 684, 687, 690, 693, 696, 699, 702, 705, 897, 900, 903, 906. 909, 912, 915, 918, 921, 924, 927. 930, 933, 936, 939, 942, 945, 948, 951, 954, 957, 960, 963, 966, 969, 972, 975, 978, 981, 984.
Harlem river.......	11	2.18	33	353, 637, 640, 985, 988, 991, 994, 997, 1000, 1298.	8	1.56	28	638, 641, 986, 989, 992, 995, 998, 1001.	9	1.71	31	639, 642, 987, 990, 993, 996, 999, 1002, 1297.
Kill van Kull.......	38	3.89	65	319, 329, 339, 345, 388, 403, 421, 436, 823, 826, 829, 832, 835, 838, 841, 844, 847, 850, 853, 856, 859, 862, 865, 868, 871, 874, 877, 880, 883, 886, 889, 892, 1276, 1291, 1315, 1330, 1348, 1363.	34	3.58	64	387, 404, 422, 437, 824, 827, 830, 833, 836, 839, 842, 845, 848, 851, 854, 857, 860, 863, 866, 869, 872, 875, 878, 881, 884, 887, 890, 893, 1277, 1292, 1316, 1331, 1349, 1364.	38	4.05	68	320, 330, 340, 346, 390, 405, 423, 438, 825, 828, 831, 834, 837, 840, 843, 846, 849, 852, 855, 858, 861, 864, 867, 870, 873, 876, 879, 882, 885, 888, 891, 894, 1278, 1293, 1317, 1332, 1350, 1365.
The Narrows.......	59	3.95	69	321, 331, 341, 343, 385, 400, 424, 439, 538, 541, 544, 547, 550, 553, 556, 559, 562, 565, 568, 571, 574, 577, 580, 583, 586, 589, 592, 595, 598, 601, 604, 607, 610, 1207, 1210, 1213, 1216, 1219, 1222, 1225, 1228, 1231, 1234, 1237, 1240, 1243, 1246, 1249, 1252, 1255, 1258, 1261, 1264, 1279, 1294, 1318, 1333, 1351, 1366.	55	3.91	71	386, 401, 425, 440, 539, 542, 545, 548, 551, 554, 557, 560, 563, 566, 569, 572, 575, 578, 581, 584, 587, 590, 593, 596, 599, 602, 605, 608, 611, 1208, 1211, 1214, 1217, 1220, 1223, 1226, 1229, 1232, 1235, 1238, 1241, 1244, 1247, 1250, 1253, 1256, 1259, 1262, 1265, 1280, 1295, 1319, 1334, 1352, 1367.	59	4.43	78	322, 332, 342, 344, 387, 402, 426, 441, 540, 543, 546, 549, 552, 555, 558, 561, 564, 567, 570, 573, 576, 579, 582, 585, 588, 591, 594, 597, 600, 603, 606, 609, 612, 1209, 1212, 1215, 1218, 1221, 1224, 1227, 1230, 1233, 1236, 1239, 1242, 1245, 1248, 1251, 1254, 1257, 1260, 1263, 1266, 1281, 1296, 1320, 1335, 1353, 1368.
Gowanus canal.....	2	4.80	63	356–357.	—	—	—	No mid-depth samples.	—	—	—	No deep samples.
Newtown creek.....	3	1.40	18	374–376.	—	—	—	No mid-depth samples.	—	—	—	No deep samples.
Wallabout canal. ..	2	4.68	61	372–373.	—	—	—	No mid-depth samples.	—	—	—	No deep samples.

TABLE CXXVIII

Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1913
Averages of samples taken on Ebb and Flood Currents for various parts of the harbor

Data for this table are contained in Table CXXV.

Location	Currents							
	Ebb Currents				Flood Currents			
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	Samples included in the averages
Upper bay	34	4.51	75	327–328, 337–338, 406–408, 433–435, 811–822, 1288–1290, 1312–1314, 1345–1347, 1360–1362.	31	3.89	63	317–318, 347–348, 391–393, 418–420, 796–810, 1273–1275, 1327–1329.
Hudson river, below Spuyten Duyvil	109	3.55	59	325–326, 335–336, 366–371, 379–384, 409–411, 745–795, 1087–1116, 1285–1287, 1309–1311, 1357–1359.	62	2.92	48	315–316, 349–350, 354, 394–396, 415–417, 430–432, 706–744, 1270–1272, 1324–1326, 1342–1344.
Hudson river, above Spuyten Duyvil	30	4.15	72	1018–1047.	54	4.93	85	1003–1017, 1048–1086.
East river, below Hell Gate	129	2.69	45	323–324, 333–334, 355, 360–365, 377–378, 451–480, 529–537, 613–636, 1132–1173, 1282–1284, 1299, 1305–1308, 1354–1356.	131	2.38	40	313–314, 351–352, 358–359, 397–399, 412–414, 427–429, 443–450, 481–528, 1117–1131, 1174–1206, 1267–1269, 1302–1304, 1321–1323, 1339–1341.
East river, above Hell Gate	72	3.97	70	679–705, 895–939.	81	3.64	64	643–678, 940–984.
Harlem river	26	1.56	28	637–642, 985–1002, 1297–1298.	1	5.40	68	353.
Kill van Kull	64	3.82	66	329–330, 339–340, 403–405, 436–438, 823–828, 859–894, 1291–1293, 1330–1332, 1348–1350, 1363–1365.	46	3.89	66	319–320, 345–346, 388–390, 421–423, 829–858, 1276–1278, 1315–1317.
The Narrows	91	4.33	77	331–332, 341–342, 400–402, 439–441, 538–579, 1237–1266, 1279–1281, 1333–1335, 1351–1353.	82	3.85	68	321–322, 343–344, 385–387, 424–426, 580–612, 1207–1236, 1279–1281, 1318–1320, 1366–1368.
Gowanus canal	2	4.80	63	356–357.	—	—	—	No flood samples.
Newtown creek	3	1.40	18	374–376.	—	—	—	No flood samples.
Wallabout canal	2	4.68	61	372–373.	—	—	—	No flood samples.

TABLE CXXIX

Average Volume and Percentage of Saturation of Dissolved Oxygen in the Water in the Year 1913
Summary of Tables CXXVI, CXXVII and CXXVIII

Data for this table are contained in Table CXXV.

Location	All Depths and Tides			Depths									Currents					
				Surface			Mid-depth			Bottom			Ebb			Flood		
	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent. saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation	No. of analyses	Averages: C. C. per litre	Averages: per cent saturation
Upper bay	65	4.21	70	23	4.09	66	19	3.93	69	23	4.57	74	34	4.51	75	31	3.89	63
Hudson river, below Spuyten Duyvil	171	3.33	54	63	3.56	57	52	3.10	53	56	3.27	54	109	3.55	59	62	2.92	48
Hudson river, above Spuyten Duyvil	84	4.65	81	28	4.80	83	28	4.57	79	28	4.59	80	30	4.15	72	54	4.93	85
East river, below Hell Gate	260	2.53	43	93	2.70	43	84	2.26	40	83	2.62	46	129	2.69	45	131	2.38	40
East river, above Hell Gate	153	3.80	67	51	3.64	64	51	3.76	67	51	3.98	70	72	3.97	70	81	3.64	64
Harlem river	27	1.70	29	10	1.80	29	8	1.56	28	9	1.71	31	26	1.56	28	1	5.40	68
Kill van Kull	110	3.85	66	38	3.89	65	34	3.58	64	38	4.05	68	64	3.82	66	46	3.89	66
The Narrows	173	4.10	73	59	3.95	69	55	3.91	71	59	4.43	78	91	4.33	77	82	3.85	68
Gowanus canal	2	4.80	63	2	4.80	63	No mid-depth samples.			No deep samples.			2	4.80	63	No flood samples.		
Newtown creek	3	1.40	18	3	1.40	18	No mid-depth samples.			No deep samples.			3	1.40	18	No flood samples.		
Wallabout canal	2	4.68	61	2	4.68	61	No mid-depth samples.			No deep samples.			2	4.68	61	No flood samples.		

NOTE.—Total	1050	Number of samples included in the averages.
	1	No. 442 not used, being too near Manhattan sewer outlet at Brooklyn Bridge.
	2	Nos. 1300–1301 not used, because aerated before analysis.
	3	Nos. 1336–1338 not used, as they apply to harbor water in general, and to no particular locality.
	1056	Total analyses during 1913, Nos. 313–1368. Series for 1913 begins with sample No. 313.

INTRODUCTION TO TABLE CXXX

In the year 1913, the same attention was given to the collection of samples in cross-sections of the main tidal channels in different parts of the harbor as characterized the work in 1911. The method of collecting samples in cross-sections was the same as that followed in 1911, and described in the introduction to Table XXVIII, Report of Metropolitan Sewerage Commission, 1912, pages 415-416.

Table CXXX contains a summary of averages of the oxygen found at various cross-sections in the year 1913, on the ebb currents, the flood currents, and without regard to current direction.

TABLE CXXX

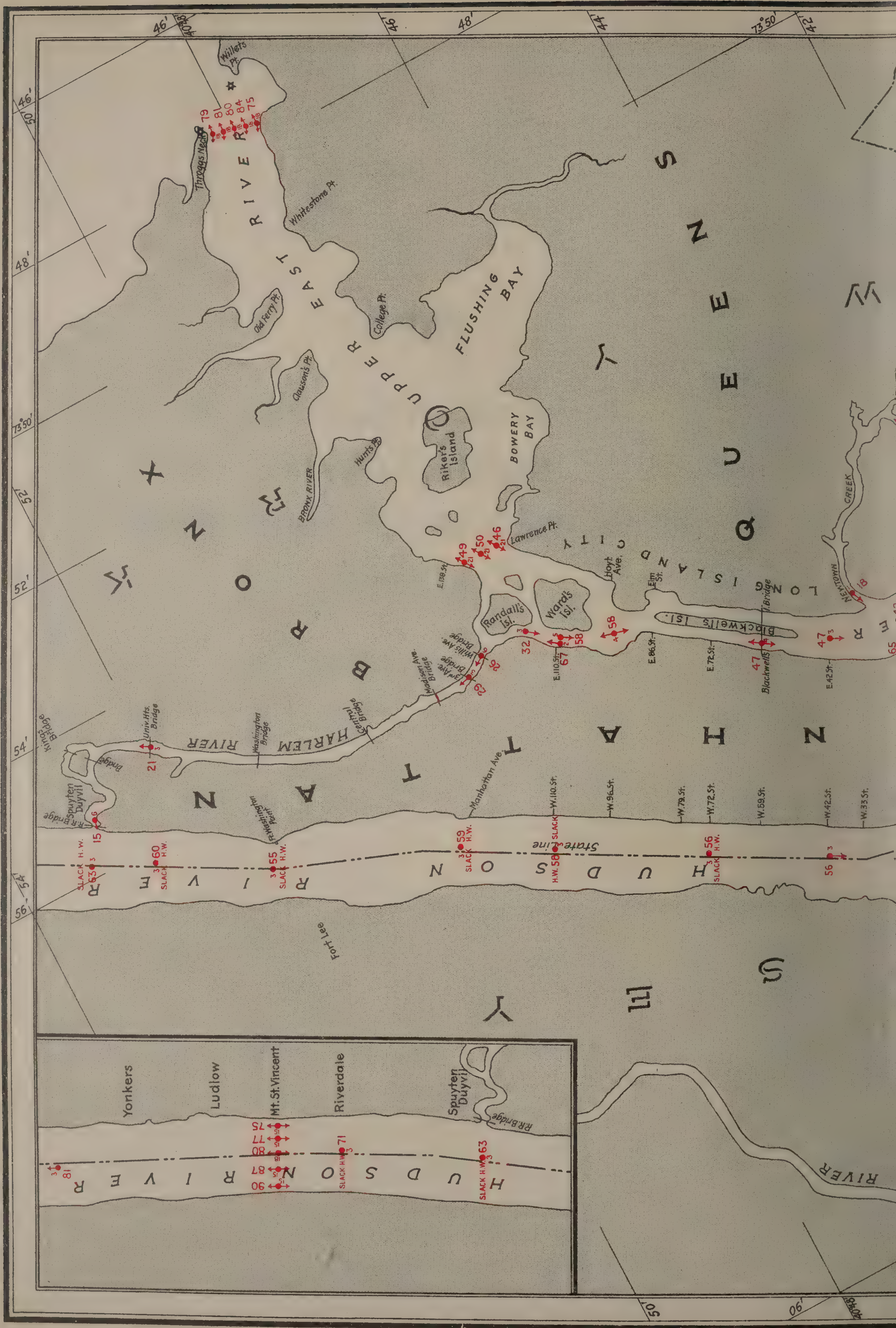
Average Volume and Percentage of Saturation of **Dissolved Oxygen in the Water** in the Year 1913
Averages of Samples taken in the Cross-sections of the Tidal Channels

Data for this table are contained in Table CXXV.

Location	Dissolved Oxygen: Both Currents		Dissolved Oxygen: Ebb Current		Dissolved Oxygen: Flood Current		Number of Samples	Date 1913	Samples included in the averages
	C. C. Per Litre	Per Cent. Saturation	C. C. Per Litre	Per Cent Saturation	C. C. Per Litre	Per Cent Saturation			
Hudson river, at Mt. St. Vincent	4.58	80	4.15	72	5.01	87	75	July 16	1003–1077.
Hudson river, at the mouth	2.68	48	3.08	55	2.28	41	90	July 9	706–795.
East river, at Throggs Neck	4.53	80	4.68	82	4.38	72	90	July 14	895–984.
East river, at Lawrence Point	2.76	49	2.79	49	2.72	48	63	July 8	643–705.
East river, at the mouth	2.21	40	2.43	44	1.98	36	87	July 2	451–537.
	2.32	42	2.51	45	2.14	38	90	July 18	1117–1206.
	2.26	41	2.47	44	2.06	37	177		
Kill van Kull, at Sailors Snug Harbor	3.61	65	3.64	66	3.58	65	72	July 11	823–894.
The Narrows, at the Forts	3.63	67	3.68	68	3.58	65	75	July 3	538–612.
	4.14	77	4.60	84	3.69	70	60	July 24	1207–1266.
	3.88	72	4.14	76	3.64	67	135		
Upper bay, in vicinity of Robbins Reef	3.78	68	4.42	80	3.13	56	27	July 10	796–822.

Plate C

Percentage of Saturation of Dissolved Oxygen in the Water of New York Harbor in 1913


UPPER EAST RIVER
FLUSHING BAY
BOWERY BAY
BRONX
QUEENS
MANHATTAN
NEW JERSEY
HUDSON RIVER
HARLEM RIVER
LONG ISLAND CITY
Throggs Neck
Willets Pt.
Whitestone Pt.
Old Ferry Pt.
College Pt.
Clason's Pt.
Hunts Pt.
BRONX RIVER
Riker's Island
Lawrence Pt.
E. 138 St.
Randall's Isl.
Ward's Isl.
Hoyt Ave.
Elm St.
Blackwell's Isl.
Blackwell's I. Bridge
NEWTOWN CREEK
E. 110 St.
E. 86 St.
E. 72 St.
E. 42 St.
Willis Ave. Bridge
3rd Ave. Bridge
Madison Ave. Bridge
Central Bridge
Washington Bridge
Univ. Hts. Bridge
Kings Bridge
Bridge
Spuyten Duyvil
R.R. Bridge
Ft. Washington Point
Manhattan Ave.
W. 110 St.
W. 96 St.
W. 79 St.
W. 72 St.
W. 59 St.
W. 42 St.
W. 33 St.
State Line
Fort Lee
SLACK H.W.
H.W.
Yonkers
Ludlow
Mt. St. Vincent
Riverdale
79
81
80
84
75
49
50
46
58
32
67
58
47
47
18
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62
63
21
15
63
60
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56
56
81
75
77
80
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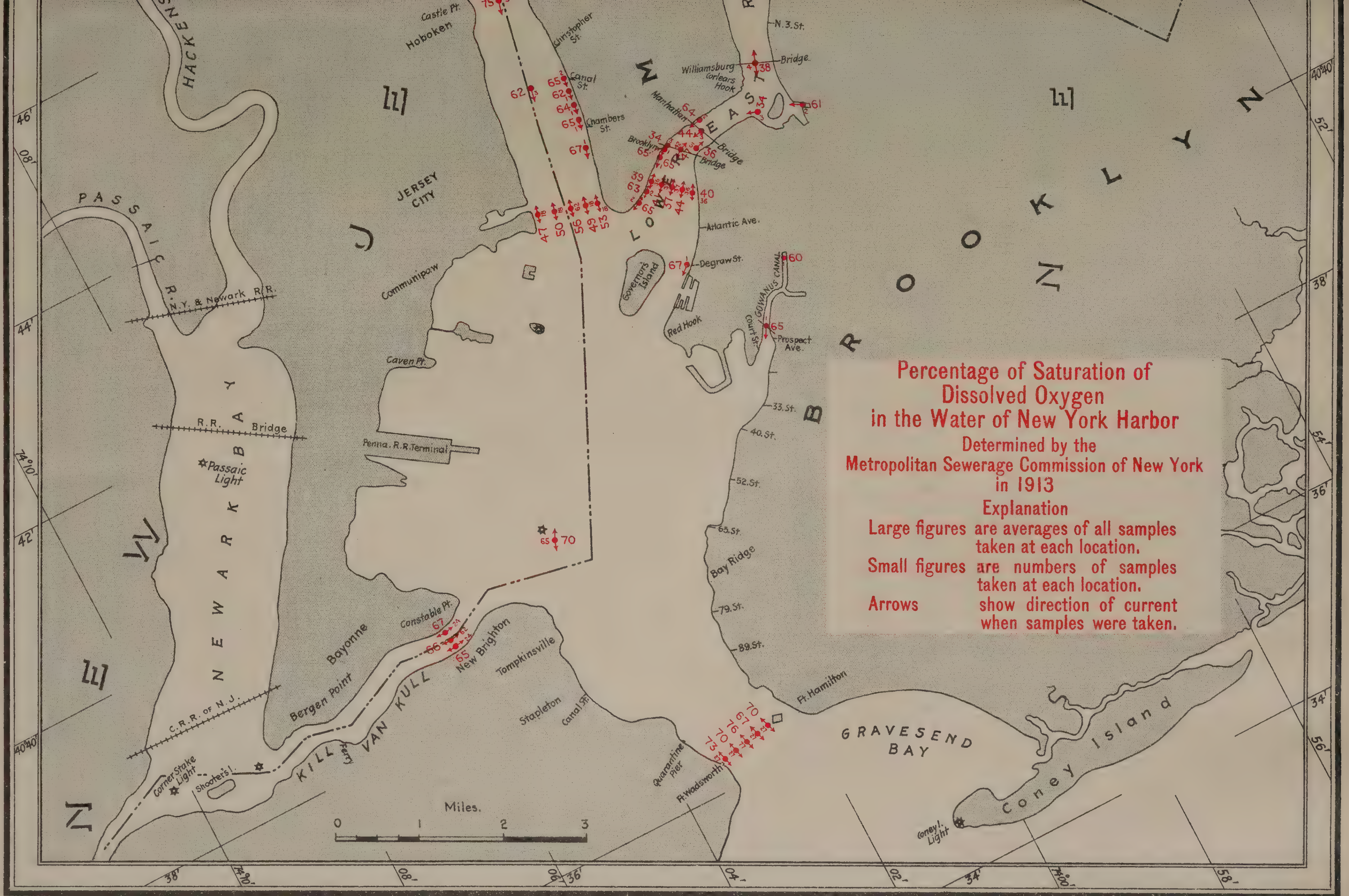
90
71
63
46'
40°38'
46'
48'
44'
73°50'
42'
50'
48'
73°50'
52'
52'
54'
54'
56'
50'
06'
40°48'



Percentage of Saturation of Dissolved Oxygen in the Water of New York Harbor

Determined by the Metropolitan Sewerage Commission of New York in 1913

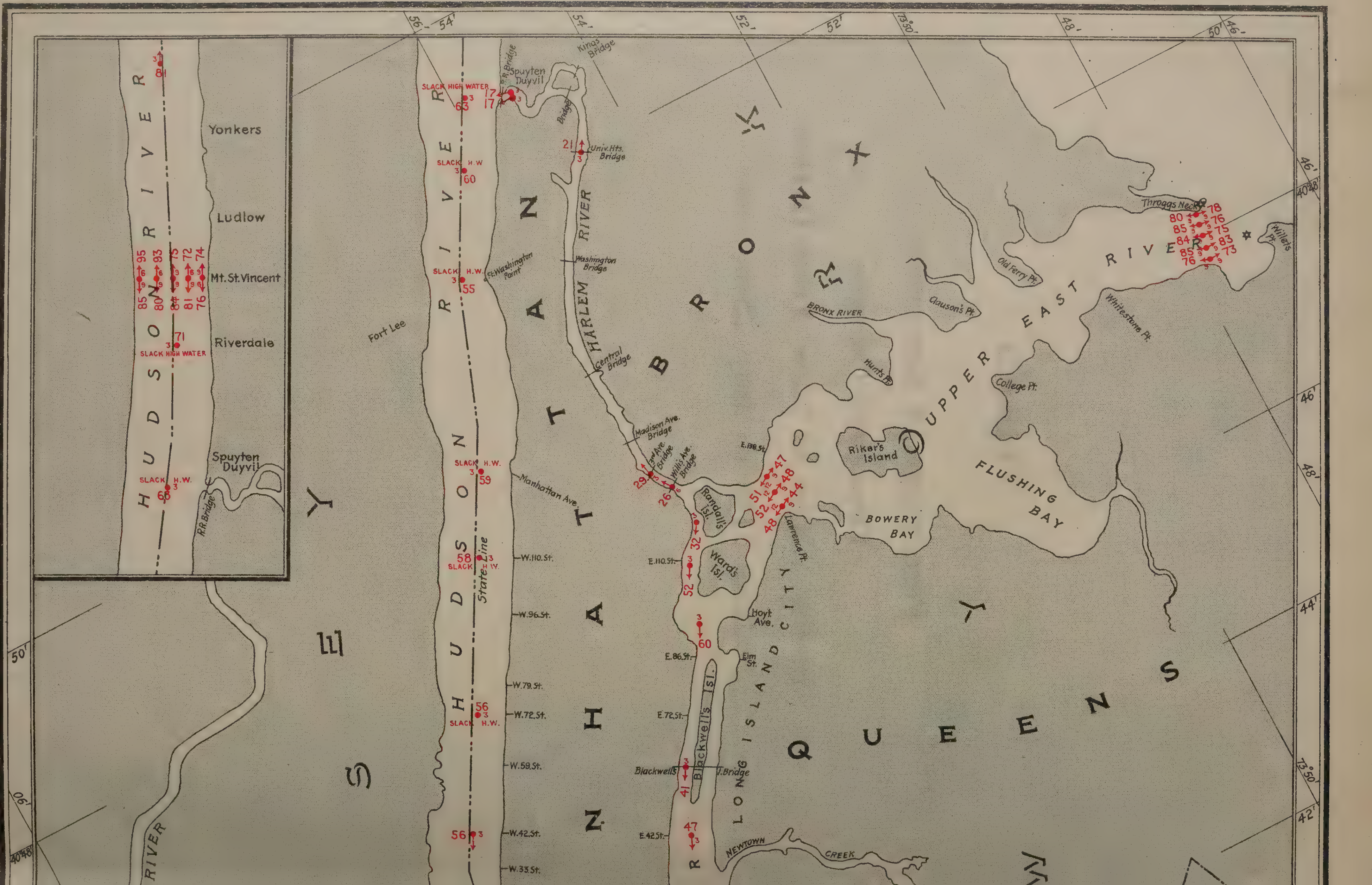
Explanation

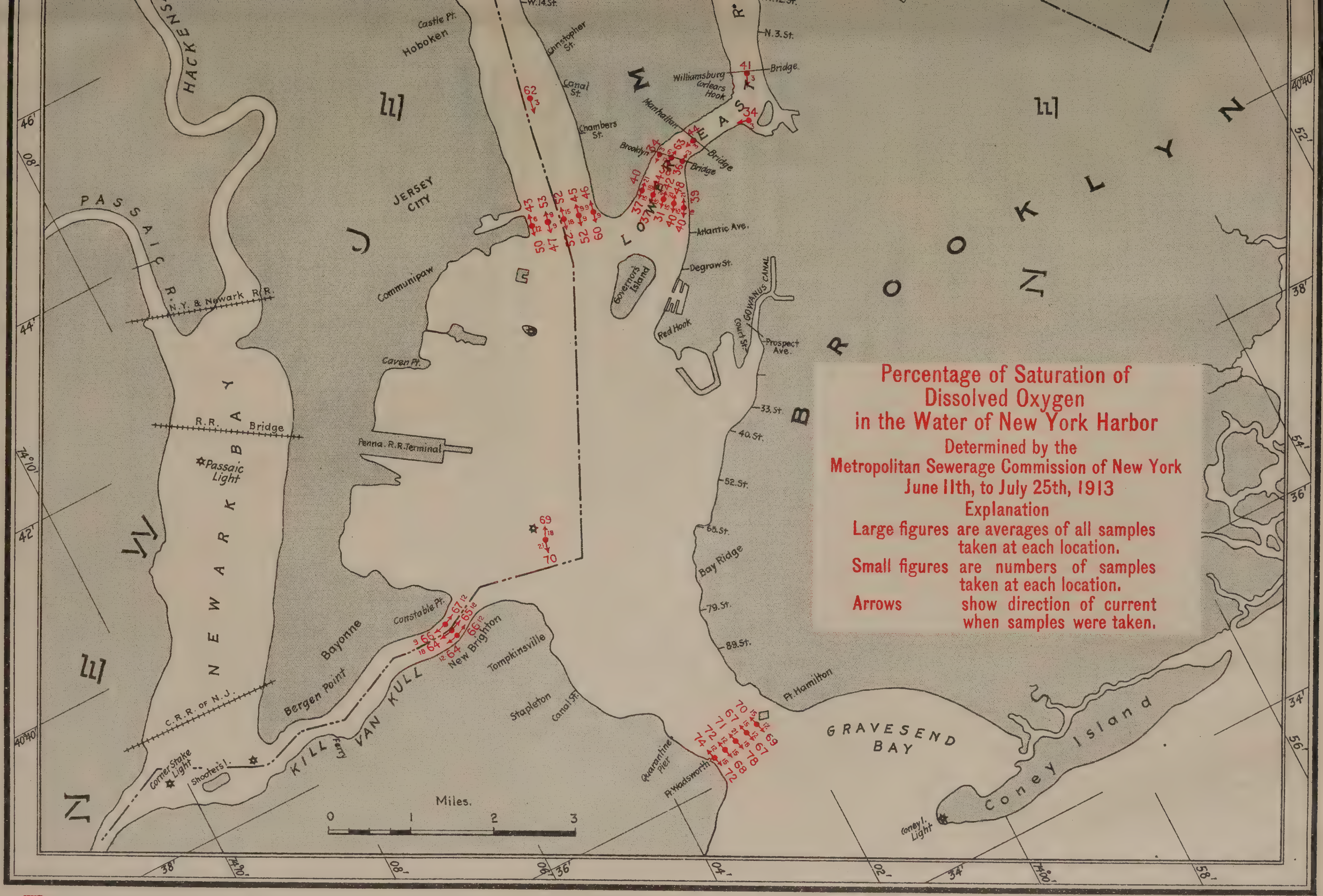
Large figures	are averages of all samples taken at each location.
Small figures	are numbers of samples taken at each location.
Arrows	show direction of current when samples were taken.

Plate D

Percentage of Saturation of Dissolved Oxygen in the Water of New York Harbor

June 11th to July 25th, 1913


BRONX
MANHATTAN
QUEENS
NEW JERSEY
HUDSON RIVER
HARLEM RIVER
UPPER EAST RIVER
FLUSHING BAY
BOWERY BAY
LONG ISLAND CITY
NEWTOWN CREEK
BRONX RIVER
Yonkers
Ludlow
Mt. St. Vincent
Riverdale
Spuyten Duyvil
R.R. Bridge
Kings Bridge
Bridge
Univ. Hts. Bridge
Washington Bridge
Central Bridge
Madison Ave. Bridge
3rd Ave. Bridge
Willis Ave. Bridge
Ft. Washington Point
Fort Lee
Manhattan Ave.
State Line
SLACK HIGH WATER
SLACK H.W.
SLACK N.Y.
W. 110 St.
W. 96 St.
W. 79 St.
W. 72 St.
W. 59 St.
W. 42 St.
W. 33 St.
E. 138 St.
E. 110 St.
E. 86 St.
E. 72 St.
E. 42 St.
Randall's Isl.
Ward's Isl.
Blackwell's Isl.
Blackwell's Bridge
Riker's Island
Hoyt Ave.
Elm St.
Lawrence Pt.
Hunts Pt.
Clauson's Pt.
Old Ferry Pt.
College Pt.
Whitestone Pt.
Throggs Neck
Willets Pt.
56' 54' 52' 50' 48' 46' 44' 42'
73°50'
40°48'
06'
81
63
17
21
60
55
59
58
56
71
68
95 93 75 72 74
85 80 84 81 76
29
26
32
52
60
41
47
51 52 48
47 48 44
80 85 84 85 76
78 76 75 83 73
3
6
9
12



Percentage of Saturation of Dissolved Oxygen in the Water of New York Harbor

Determined by the Metropolitan Sewerage Commission of New York

June 11th, to July 25th, 1913

Explanation

Large figures	are averages of all samples taken at each location.
Small figures	are numbers of samples taken at each location.
Arrows	show direction of current when samples were taken.

D

INTRODUCTION TO OXYGEN DIAGRAMS

From the data contained in Table CXXV curves have been drawn to show the variations in oxygen which occurred in one tidal cycle in the cross-sections of the Narrows, the Hudson river at the mouth and at Mt. St. Vincent, and the East river at the mouth and at Throgs Neck, in the year 1913, after the same manner as shown for the year 1911, Report of Metropolitan Sewerage Commission, 1912, pages 447-457

Two groups of curves have been drawn for each section. In one the ordinates represent the percentages of saturation of dissolved oxygen in the water and the percentages of sea-water, and the abscissæ the hours of the day. Times of ebb and flood currents are indicated on the curves. Curves have been drawn for each of the three or five locations at which samples were collected in the cross-section, the heavy lines representing percentages of saturation of dissolved oxygen, and the light lines percentages of sea-water.

The second set of curves has been drawn to show the variations in dissolved oxygen and percentage of sea-water at each cross-section, as determined by each set of samples. These curves approximately indicate lines of equal oxygen and sea-water.

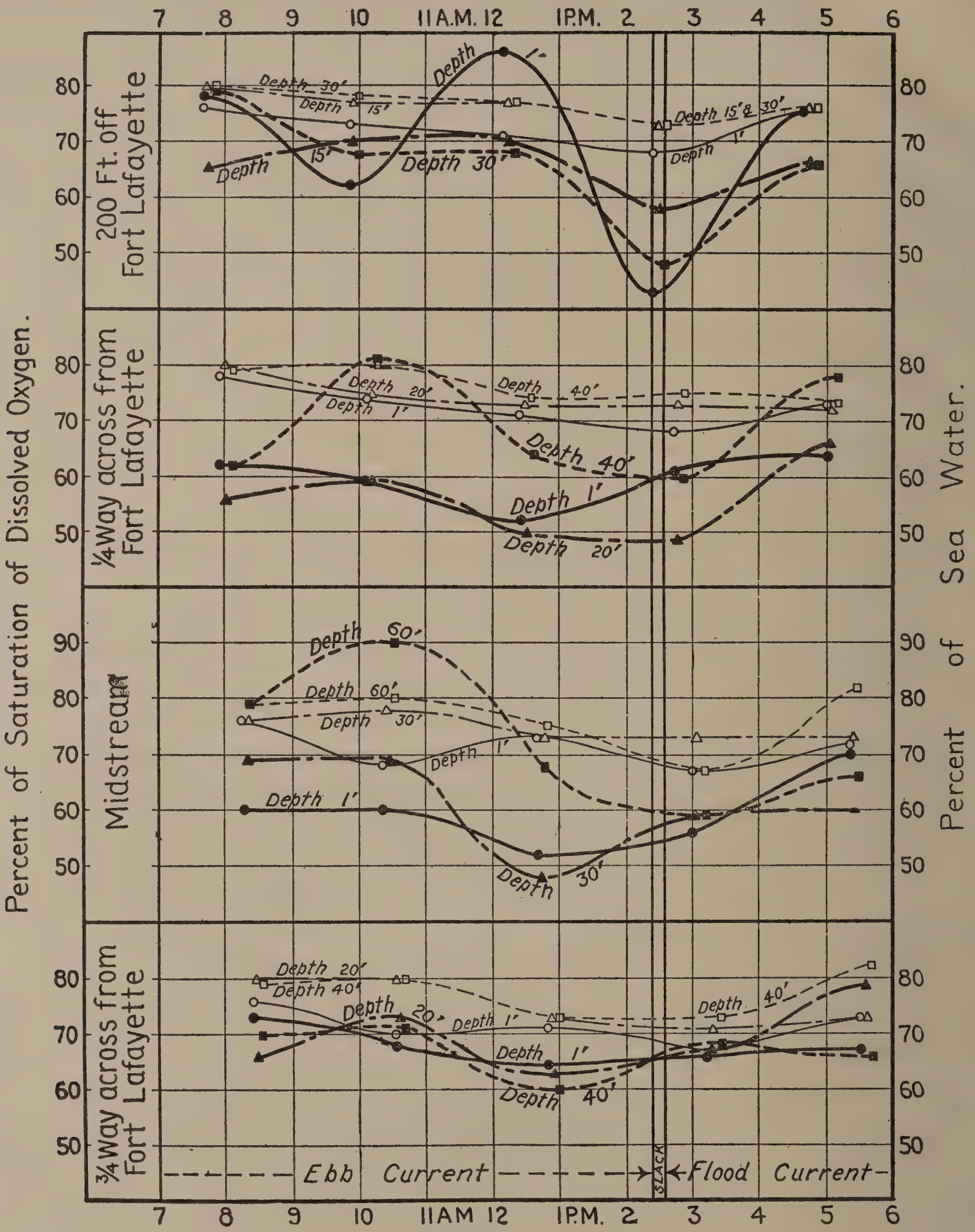


FIG. 46

Percentage of Saturation of Dissolved Oxygen in Heavy Lines, and Percentage of Sea Water in Light Lines, in a Cross-Section of the Narrows from Fort Wadsworth to Fort Lafayette at Various Stages of Tide, July 3, 1913. The Total Number of Samples included is 75. The Results of Analysis are indicated by Small Circles, Triangles and Squares.

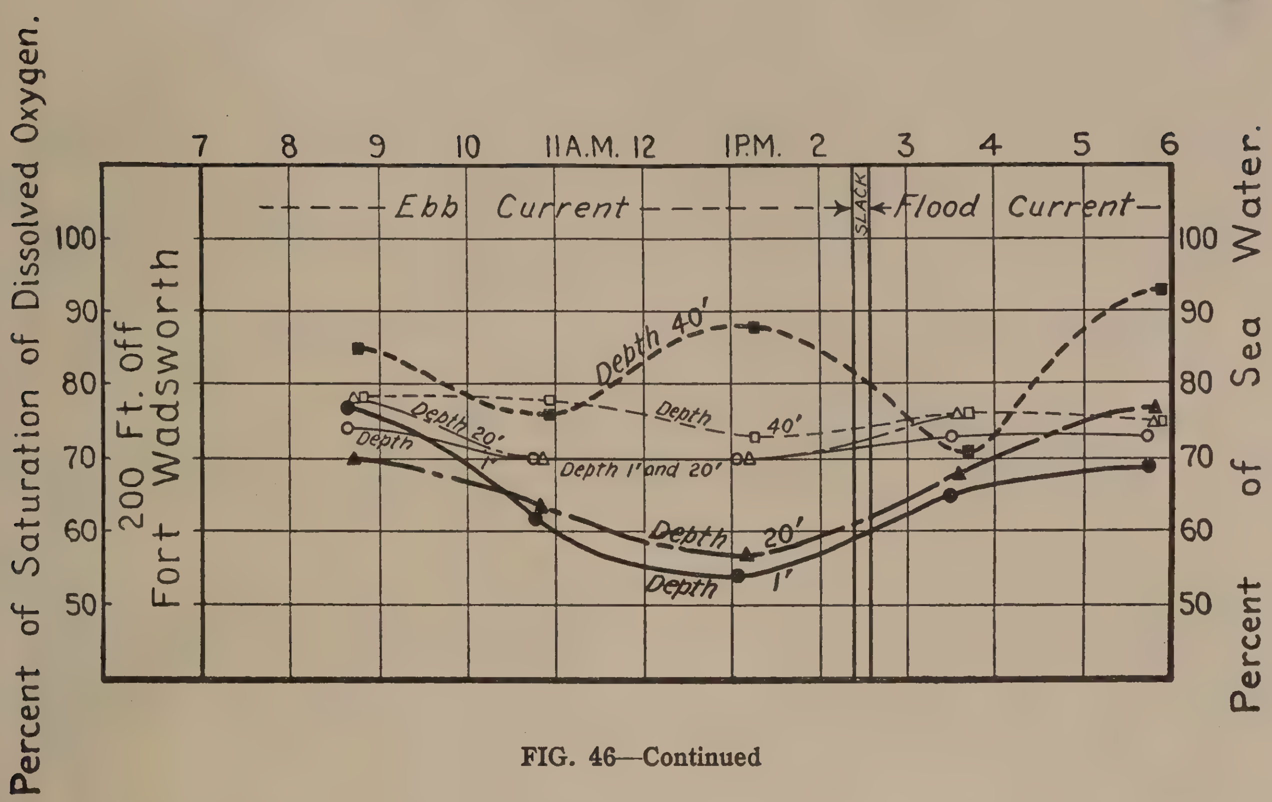


FIG. 46—Continued

COMPARISON OF THE CURVES OF DATA FOR THE NARROWS IN 1911 AND 1913.

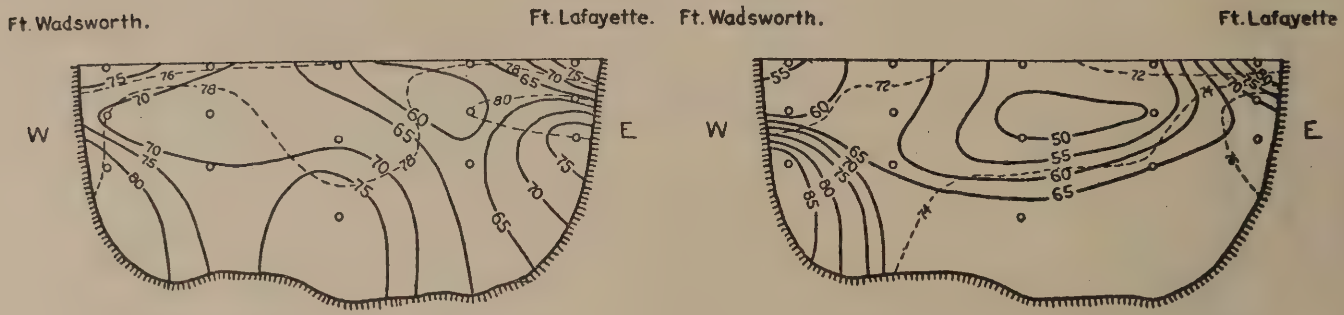
On comparing the curves made from data collected at the Narrows in 1911 and 1913, various interesting points of similarity and difference are observable. See the following diagrams in this report and Oxygen Diagrams II in Part III, Chapter III, p. 448, of the Commission's report of August, 1912.

There was less similarity between the curves at the various stations and the cross-sections in 1913 than in 1911.

The curve representing the oxygen at depths of 1 foot shows that a greater range of oxygen values existed in 1913 than in 1911, and there was less agreement with the curves at the other depths in 1913.

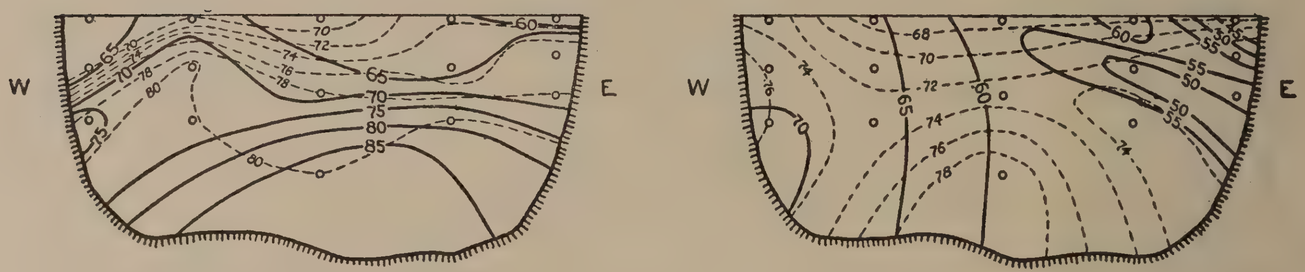
The curves representing the conditions at mid-depth and bottom were not as nearly identical in 1913 as they were in 1911. In 1913 the changes were more abrupt than in 1911 and not simultaneous at different stations and at different depths.

In both years there was a similar drop in the percentage of oxygen on the ebb current, but in 1913 it was greater in amount, more abrupt and did not follow the change of current from flood to ebb as closely as it did in 1911.



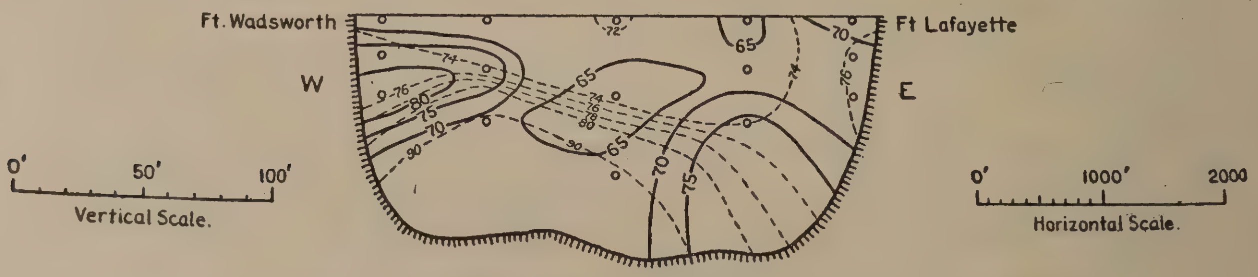
7:40 – 8:45 A.M.
(15 Samples, Nos. 538–552.)
Slack Water – End of Flood Current.

12:10 – 1:05 P.M.
(15 Samples, Nos. 568–582.)
4 Hours After Beginning of Ebb Current.



9:52 – 10:55 A.M.
(15 Samples, Nos. 553–567.)
2 Hours After Beginning of Ebb Current

2:25 – 3:40 P.M.
(15 Samples, Nos. 583–597.)
Beginning of Flood Current.



4:40 – 5:55 P.M.
(15 Samples, Nos. 598–612.)
$2\frac{1}{2}$ Hours After Beginning of Flood Current.

FIG. 47

Cross-Section of the Narrows from Fort Wadsworth to Fort Lafayette, showing Percentage of Saturation of Dissolved Oxygen in Full Lines and Percentage of Sea Water in Broken Lines, at Various Stages of Tide, July 3, 1913. The Total Number of Samples included is 75. Sampling Points are indicated by Small Circles.

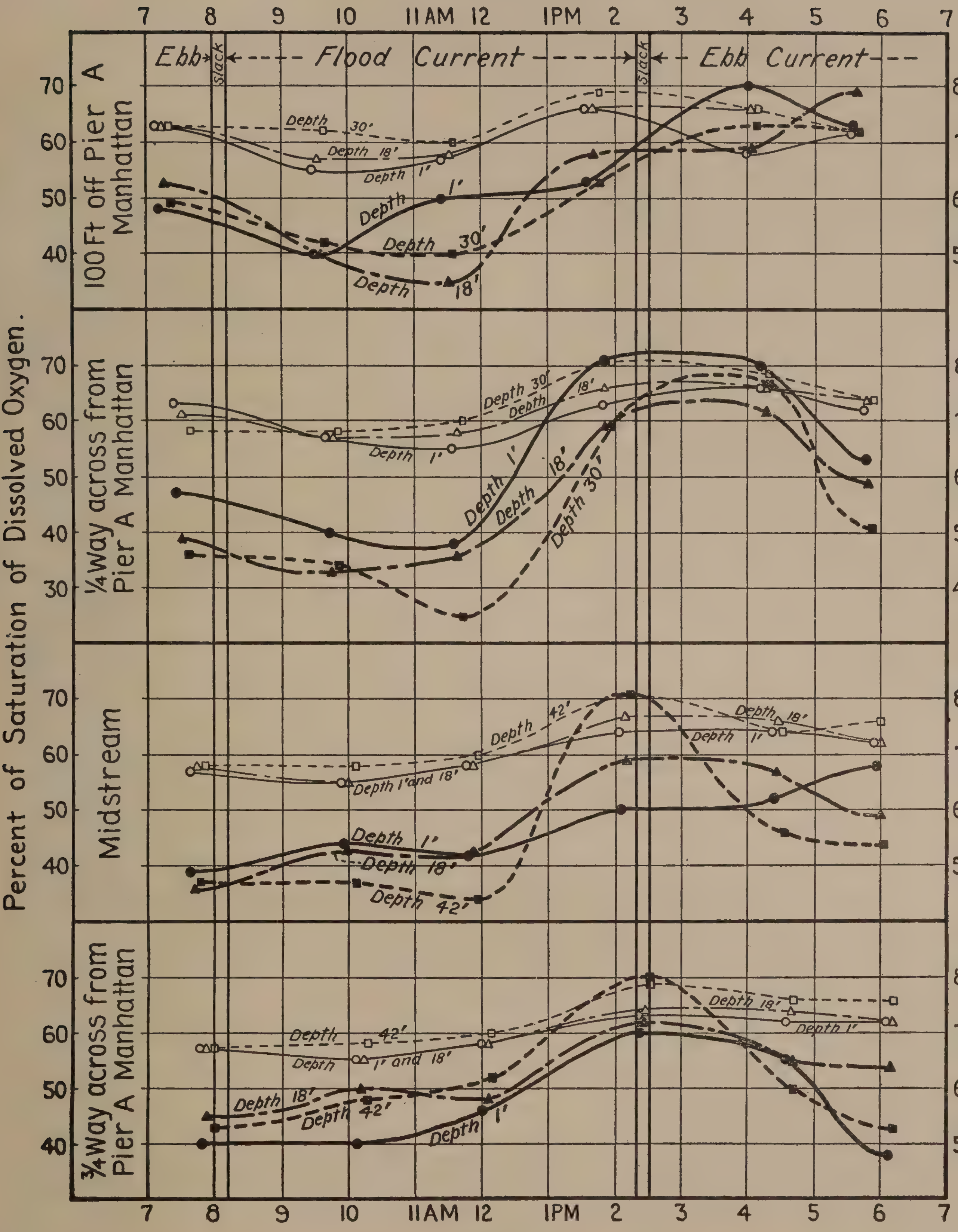


FIG. 48

Percentage of Saturation of Dissolved Oxygen in Heavy Lines, and Percentage of Sea Water in Light Lines, in a Cross-Section of the Mouth of the Hudson River, from Pier A, Manhattan, to C. R.R. of N. J. Terminal, Jersey City, at Various Stages of Tide, July 9, 1913. The Total Number of Samples included is 90. The Results of Analysis are indicated by Small Circles, Triangles and Squares.

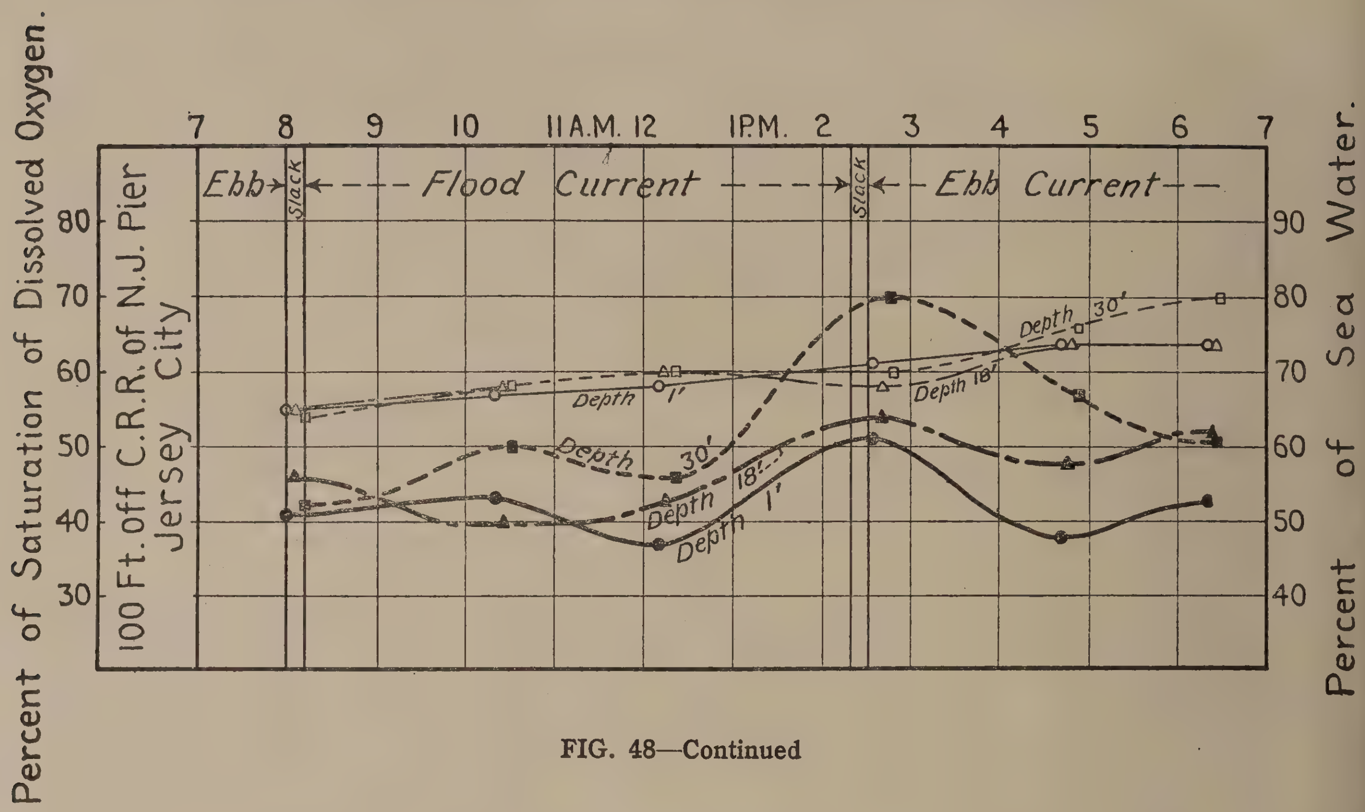


FIG. 48—Continued

COMPARISON OF THE CURVES FOR THE MOUTH OF THE HUDSON IN 1911 AND 1913.

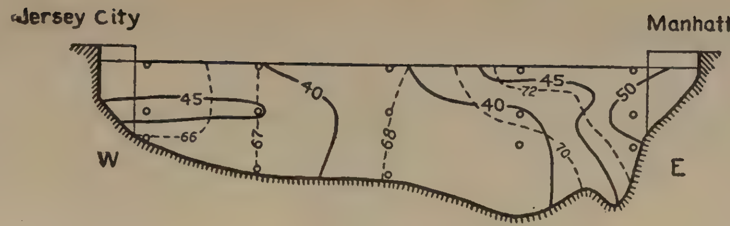
Comparing the foregoing curves with those recorded for the same section in 1911, the following deductions can be made. The 1911 curves can be found in the report of this Commission, dated August, 1912, Part III, Chapter III, p. 450.

The curves of the 1913 observations are more irregular, show more abrupt changes and cover a wider range of values than those of 1911.

The general trend of the 1-foot depth curve is followed by the mid-depth and bottom curves, though not so closely as in 1911.

In 1913 there was the same rise of oxygen values toward the end of the flood as in 1911, but it was more abrupt and did not, as a rule, reach a maximum until after the turn of the current to ebb.

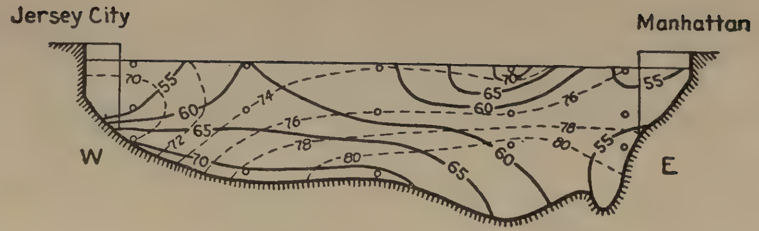
The decrease in oxygen values, which, in the 1911 curves, commenced with the slack before ebb and gradually continued, was abrupt in 1913 and delayed until about the strength of the ebb current.



7:10–8:00 A.M

(15 Samples, Nos 706–720.)

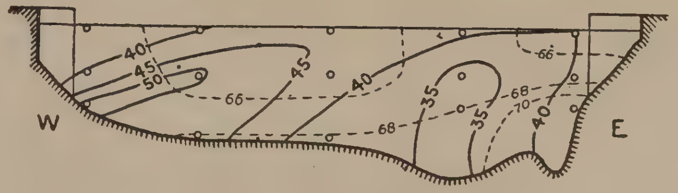
End off Ebb Current



1:35 – 2:45 P.M.

(15 Samples, Nos. 751 – 765.)

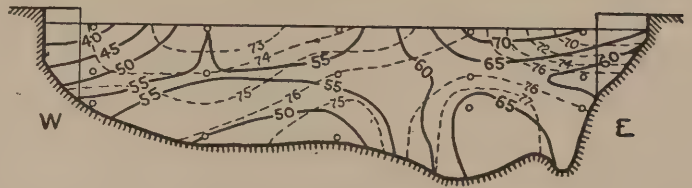
End of Flood Current.



9:30 – 10:30 A.M.

(15 Samples, Nos 721 – 735.)

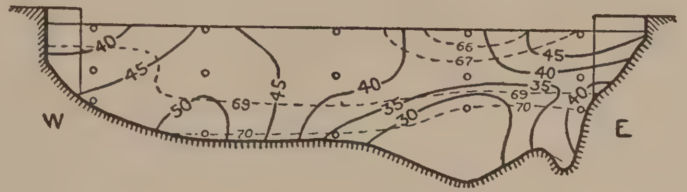
1½ Hours After Beginning of Flood Current.



4:00 – 4:50 P.M.

(15 Samples, Nos. 766 – 780.)

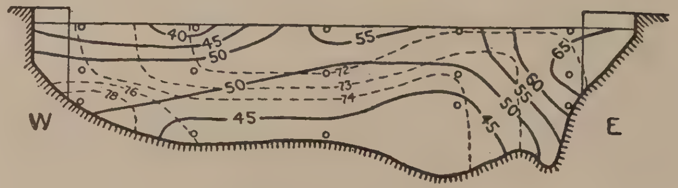
2 Hours After Beginning of Ebb Current.



11:25 – 12:20 P.M.

(15 Samples, Nos. 736 – 750.)

3½ Hours After Beginning of Flood Current



5:35 – 6:25 P.M.

(15 Samples, Nos. 781 – 795.)

4 Hours After Beginning of Ebb Current.

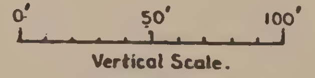


FIG. 49

Cross-Section of the Mouth of the Hudson River from Pier A, Manhattan, to C. R.R. of N. J. Terminal, Jersey City, showing Percentage of Saturation of Dissolved Oxygen in Full Lines and Percentage of Sea Water in Broken Lines, at Various Stages of Tide, July 9, 1913. The Total Number of Samples included is 90. Sampling Points are indicated by Small Circles.

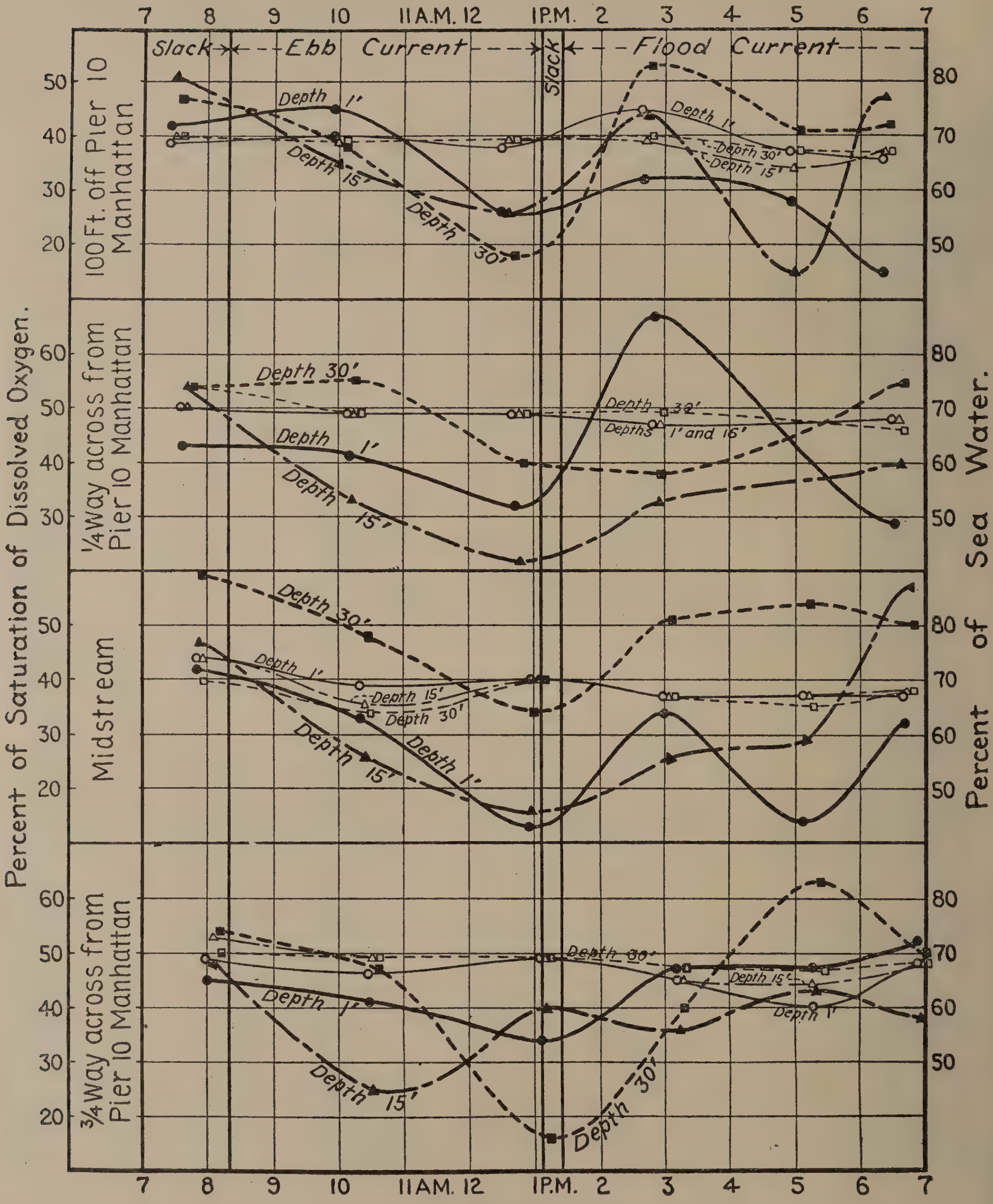


FIG. 50

Percentage of Saturation of Dissolved Oxygen in Heavy Lines, and Percentage of Sea Water in Light Lines, in a Cross-Section of the Mouth of the East River from Pier 10, Manhattan, to Pier 10, Brooklyn, at Various Stages of Tide, July 2, 1913. The Total Number of Samples included is 90. The Results of Analysis are indicated by Small Circles, Triangles and Squares.

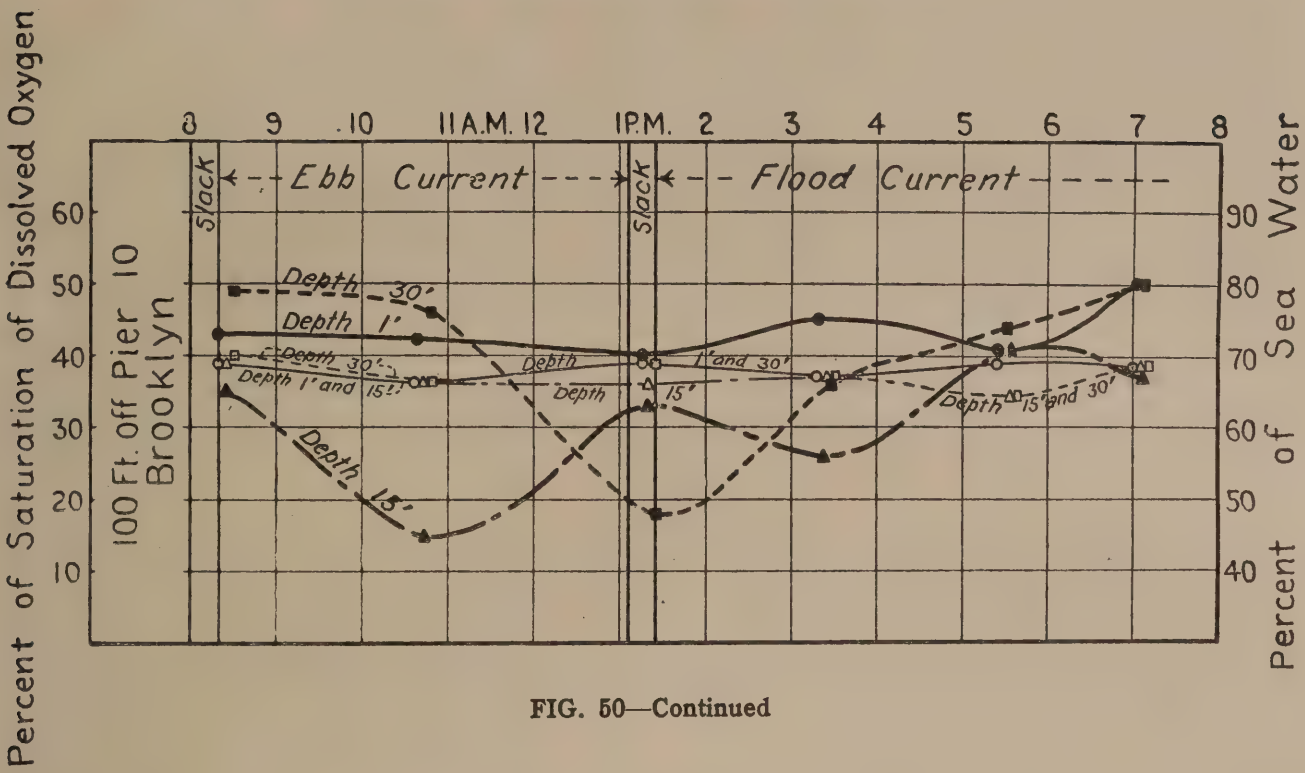


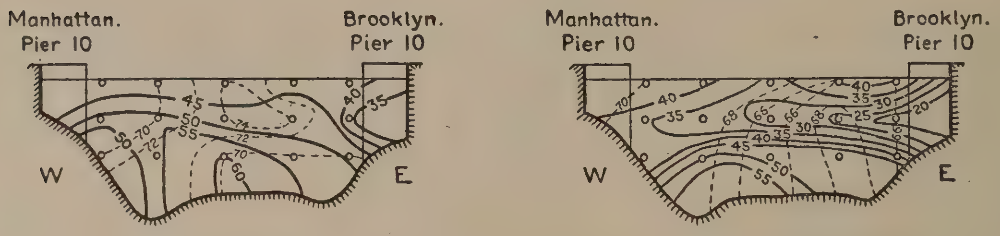
FIG. 50—Continued

Comparison of the Curves for the Mouth of the East River in 1911 and 1913

On comparing the curves published in the Commission's 1912 report, Part III, Chapter III, p. 452, with the foregoing curves for the same section, the following points become apparent.

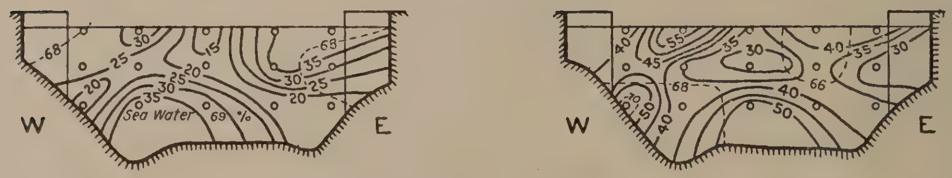
The range of oxygen values in 1911 was scarcely 10 per cent., whereas in 1913 it was nearly 50 per cent. of the saturation value.

In 1911 the curves were regular, showing a uniform rise during the flood current and a decrease in oxygen, though less gradual, throughout the ebb. In 1913 there was a decrease in oxygen, though much more rapid and less concordant at the different depths throughout the ebb current than in 1911. In 1913 the general tendency of the bottom and mid-depth curves on the flood current was to rise, while the surface curve rose rapidly to a maximum and fell off again.



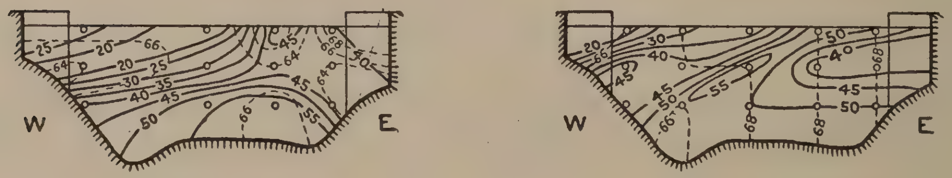
7:25 – 8:30 A.M
(15 Samples, Nos. 451 – 465.)
Slack Water – End of Flood Current.

9:55 – 10:48 A.M.
(15 Samples, Nos. 466 – 480.)
2 Hours After Beginning of Ebb Current.



12:30 – 1:25 P.M.
(15 Samples, Nos. 481 – 495.)
Slack Water – End of Ebb Current.

2:40 – 3:28 P.M.
(15 Samples, Nos 496 – 510.)
1½ Hours After Beginning of Flood Current.



4:55 – 5:31 P.M
(12 Samples, Nos 511 – 522.)
3½ Hours After Beginning of Flood Current.

6:20 – 7:10 P M
(15 Samples, Nos. 523 – 537.)
5 Hours After Beginning of Flood Current

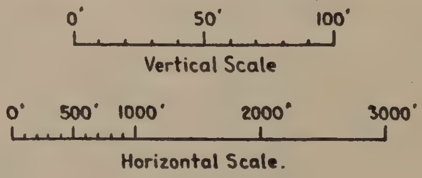


FIG. 51

Cross-Section of the Mouth of the East River from Pier 10, Manhattan, to Pier 10, Brooklyn, showing Percentage of Saturation of Dissolved Oxygen in Full Lines and Percentage of Sea Water in Broken Lines, at Various Stages of Tide, July 2, 1913. The Total Number of Samples included is 90. Sampling Points are indicated by Small Circles.

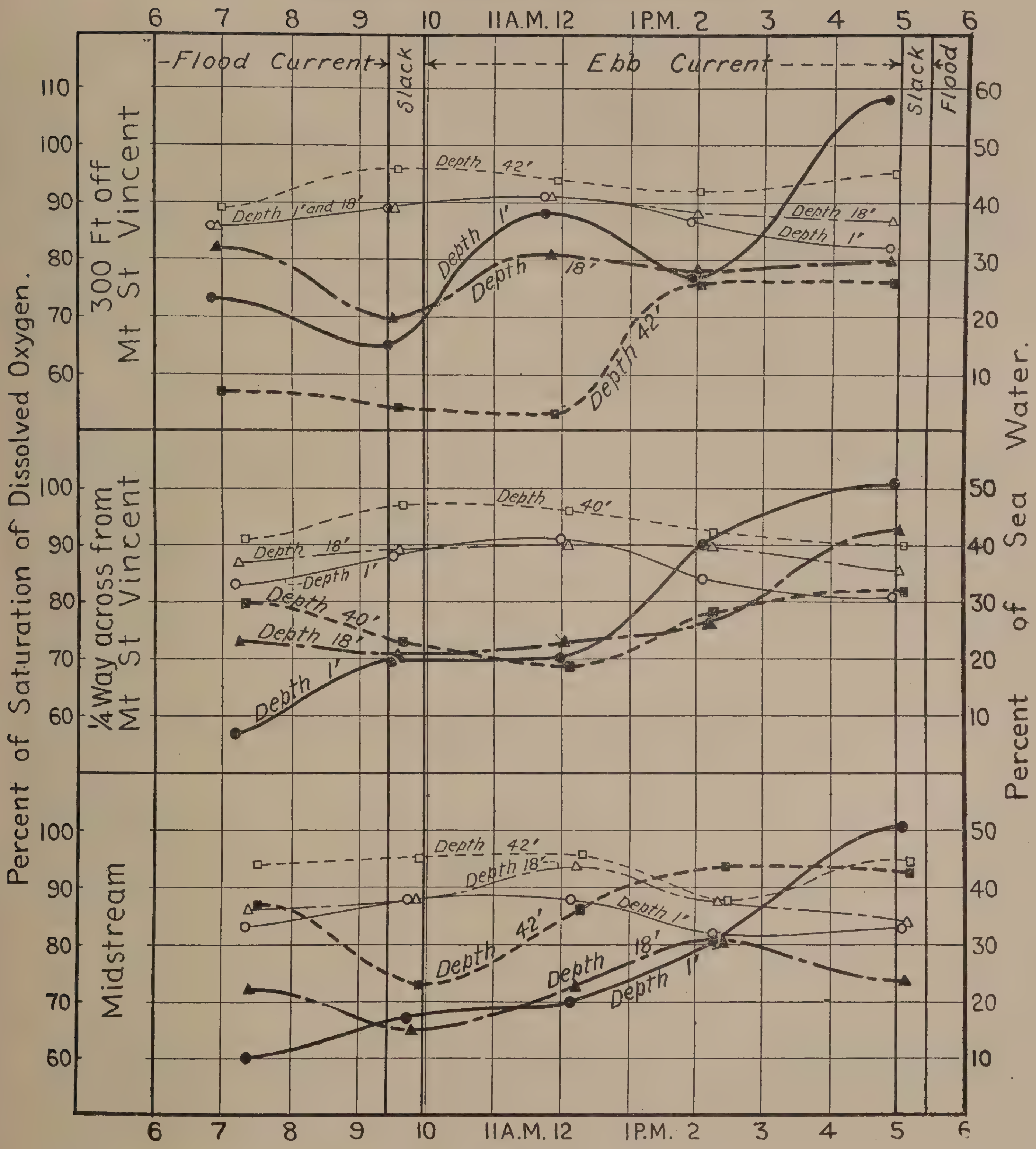


FIG. 52

Percentage of Saturation of Dissolved Oxygen in Heavy Lines, and Percentage of Sea Water in Light Lines, in a Cross-Section of the Hudson River at Mt. St. Vincent, at Various Stages of Tide, July 16, 1913. The Total Number of Samples included is 75. The Results of Analysis are indicated by Small Circles, Triangles and Squares.

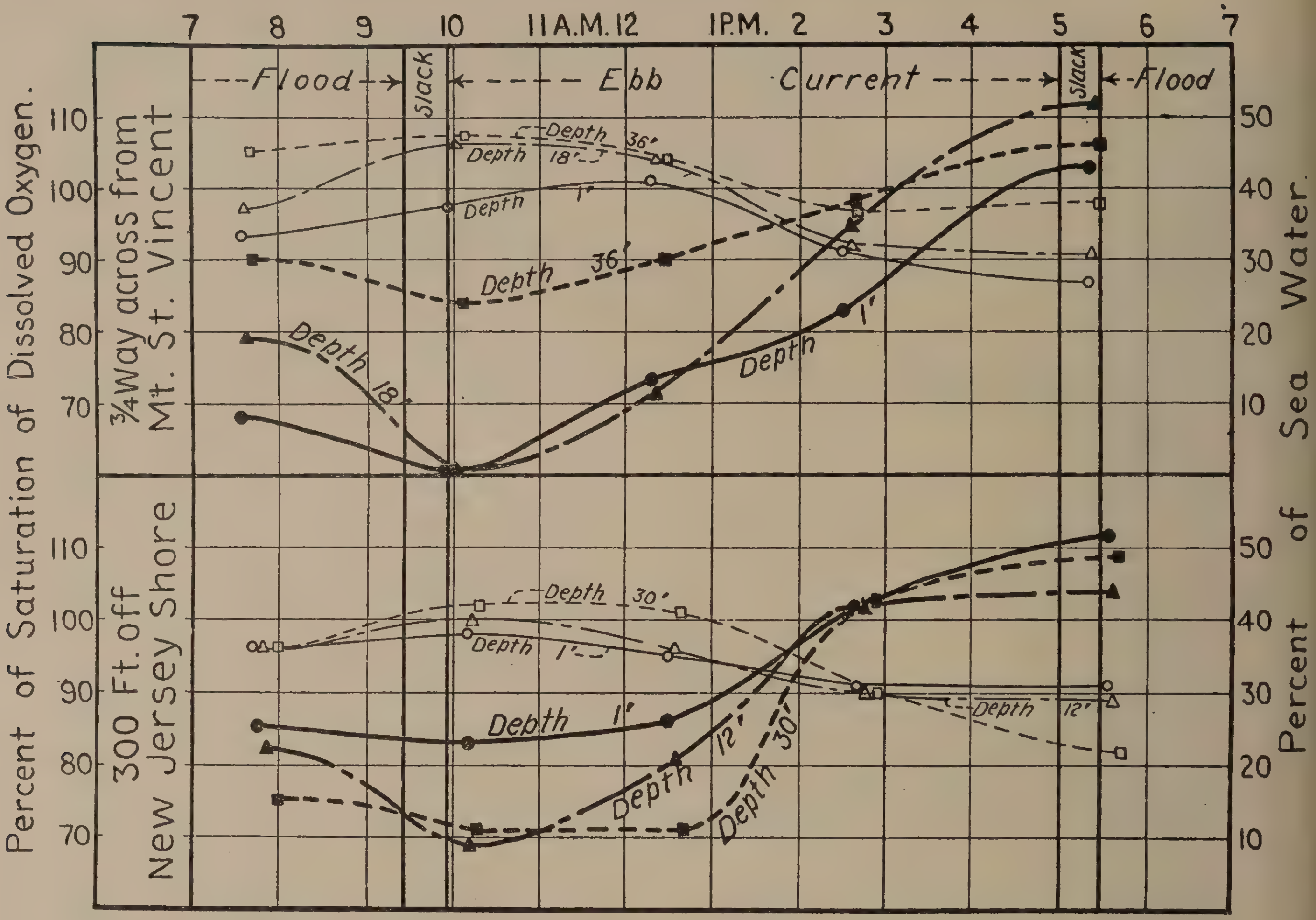


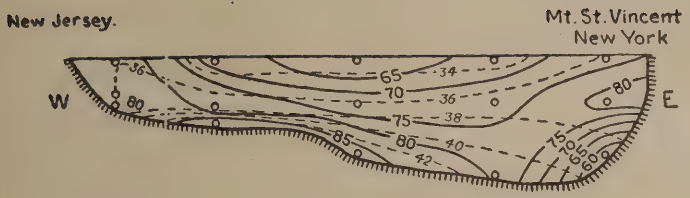
FIG. 52—Continued

Comparison of Curves of Data for the Hudson River at Mount St. Vincent in 1911 and 1913

A number of points of interest became apparent on comparing the foregoing curves with those made from data collected in the same section in 1911. The 1911 curves can be found in the report of this Commission of August, 1912, Part III, Chapter III, p. 454.

There was a greater range in the oxygen values in 1913 than in 1911. In 1911 the oxygen values were usually larger at the greater depths, while in 1913 the reverse was generally the case. In both years the variation was greater and the changes more abrupt at the surface than at the bottom or mid-depth.

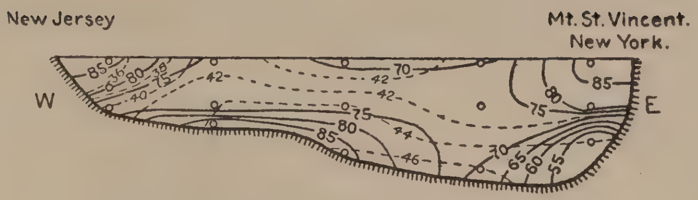
In both years there was a marked rise of oxygen on the ebb current, at all depths, probably showing that cleaner water came down from the Upper Hudson and more polluted water came up from the City of New York to the point where the oxygen determinations were made.



6:50 – 8:00 A.M.

(15 Samples, Nos. 1003–1017.)

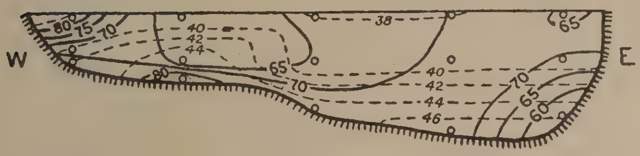
2 Hours Before End of Flood Current.



11:45 - 12:40 P M

(15 Samples, Nos. 1033–1047.)

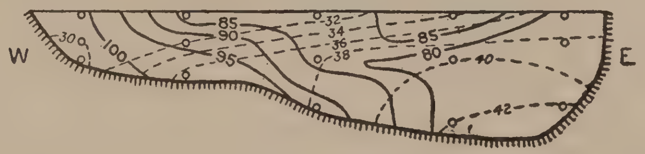
$2\frac{1}{2}$ Hours After Beginning of Ebb Current.



9:20 - 10:17 A.M

(15 Samples, Nos. 1018–1032.)

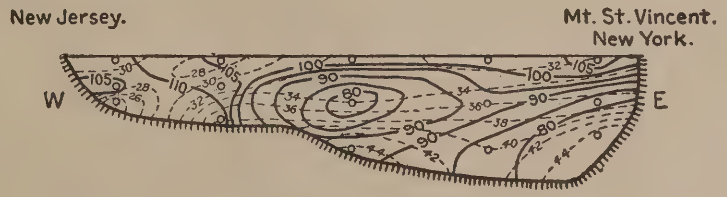
Slack Water – End of Flood Current.



1:55 - 2:50 P.M.

(15 Samples, Nos. 1048-1062.)

$4\frac{1}{2}$ Hours After Beginning of Ebb Current.



4:50 – 5:40 P.M.

(15 Samples, Nos. 1063–1077.)

Slack Water – End of Ebb Current.

FIG. 53

Cross-Section of the Hudson River at Mt. St. Vincent, showing Percentage of Saturation of Dissolved Oxygen in Full Lines, and Percentage of Sea Water in Broken Lines, at Various Stages of Tide, July 16, 1913. The Total Number of Samples included is 75. Sampling Points are indicated by Small Circles.

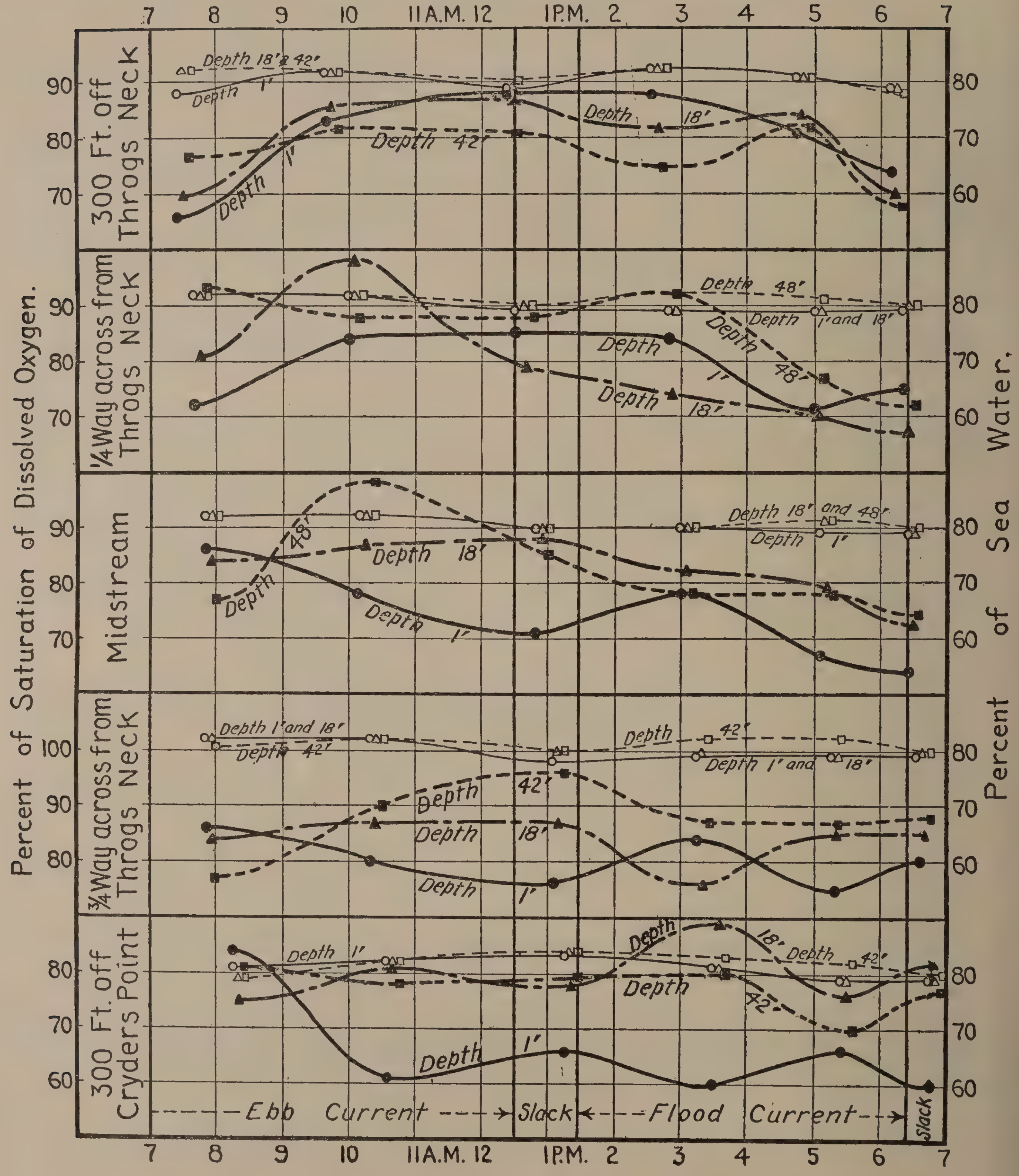
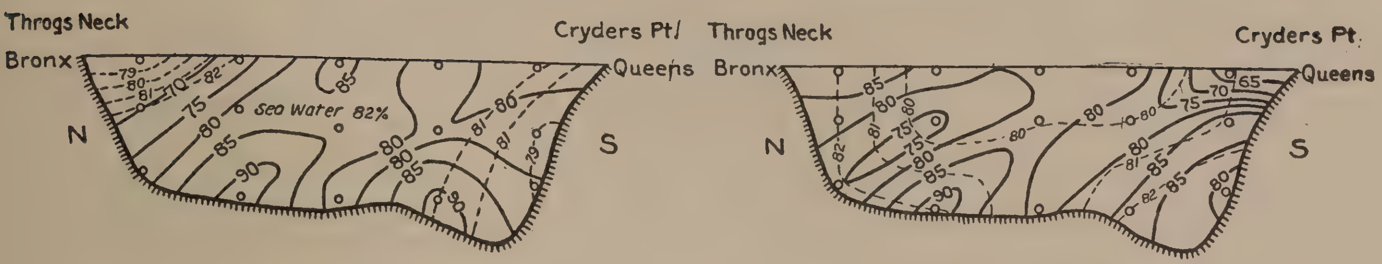


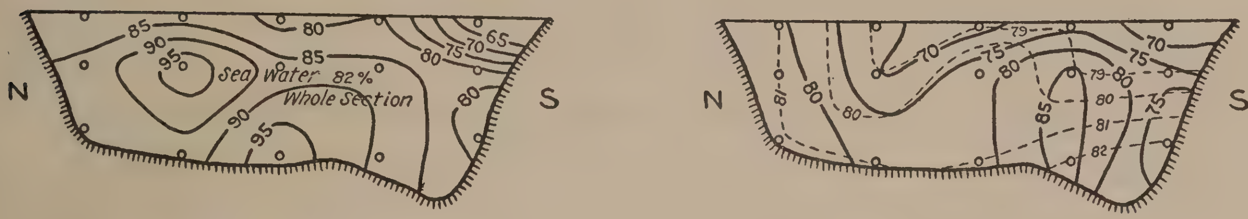
FIG. 54

Percentage of Saturation of Dissolved Oxygen in Heavy Lines, and Percentage of Sea Water in Light Lines, in a Cross-Section of the East River from Throgs Neck to Cryders Point, at Various Stages of Tide, July 14, 1913. The Total Number of Samples included is 90. The Results of Analysis are indicated by Small Circles, Triangles and Squares.



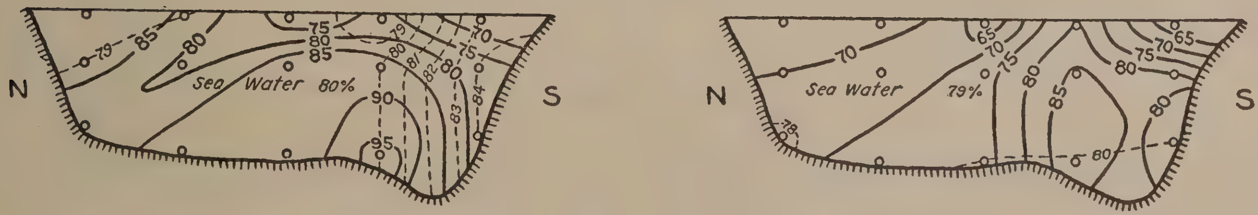
7:25 – 8:25 A.M.
(15 Samples, Nos 895 – 905.)
4½ Hours Before End of Ebb Current.

2:35 – 3:40 P.M.
(15 Samples, Nos. 940 – 954.)
1½ Hours After Beginning of Flood Current.



9:45 – 10:45 A.M.
(15 Samples, Nos. 910 – 924.)
2½ Hours Before End of Ebb Current.

4:45 – 5:35 P.M.
(15 Samples, Nos. 955 – 969.)
3½ Hours After Beginning of Flood Current.



12:25 – 1:27 P.M.
(15 Samples, Nos. 925 – 939.)
Slack Water - End of Ebb Current.

6:10 – 6:55 P.M.
(15 Samples, Nos. 970 – 984.)
Slack Water - End of Flood Current.

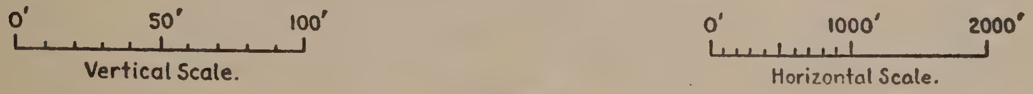


FIG. 55

Cross Section of the East River from Throgs Neck to Willets Point, showing Percentage of Saturation of Dissolved Oxygen in Full Lines, and Percentage of Sea Water in Broken Lines, at Various Stages of Tide, July 14, 1913. The Total Number of Samples included is 90. Sampling Points are indicated by Small Circles.

SECTION IV

CONSUMPTION OF DISSOLVED OXYGEN BY VARIOUS MIXTURES OF WATER, SEWAGE AND SLUDGE DURING INCUBATION

Most of the experiments described in the following pages were made in order to determine how rapidly and to what extent the oxygen dissolved in sea water, land water and New York harbor water would be consumed during incubation for seven days at temperatures ranging from 65° F. to 80° F.

In other cases sewage was added in order to measure the oxygen consuming power of the organic matter of sewage origin.

Sources of Samples

The sea water was collected off Sandy Hook and Far Rockaway, these points being selected in order that the samples might be free from pollution.

The harbor water was taken from a number of typical points located in the East river, Hudson river midway between Pier A and the docks of the Central Railroad of New Jersey, in the Upper bay at Robbins Reef, in the Kill van Kull opposite the Sailors Snug harbor, and at the Narrows midway between Forts Lafayette and Wadsworth.

The samples were collected near the surface and bottom on ebb and flood tides and at various seasons of the year.

The land water samples were drawn from the public water supply of the City of New York.

The sewage was taken from Delancey street at the corner of Pitt street. This location was chosen for sampling because the sewer drains a characteristic section of the thickly settled East Side of New York and because a weir constructed in the sewer at this point assisted the collector in getting representative samples.

Ten samples of sea water, 186 samples of harbor water, 8 samples of land water, 6 samples of sewage and one sample of harbor sludge were used in these investigations.

Consumption of Dissolved Oxygen on Incubating Sea Water

In order to determine what loss of oxygen would occur on incubating sea water which was practically free from organic matter, a sample of the water was collected on September 3, 1912, from the ocean off Far Rockaway and incubated for seventeen days at a temperature averaging 70° F. The data obtained are given in Table CXXXI.

TABLE CXXXI

Consumption of Dissolved Oxygen by Clean Sea Water Incubated for 17 Days at Room Temperature

Source of Sample	Date of Collection	Temp. Deg. C.	Specific Gravity	Aver. Temp. During Incubation Deg. C.	Dissolved Oxygen			
					C. C. per Litre			Per Cent. Lost
					Initial	After Incubation	Loss	
Ocean, off Far Rockaway....	1912 Sept. 3	20.6	1023	21.1	5.60	5.40	0.20	3.6

The data given in Table CXXXI show that the unpolluted sea water lost only a trace of its dissolved oxygen during incubation for over two weeks at an average temperature of 70° F.

Consumption of Dissolved Oxygen by Lower East River Water

In order to determine what loss of dissolved oxygen would occur during incubation in the sewage-polluted water of the Lower East river, four samples were collected on August 21, 1913, between Hell Gate and Brooklyn Bridge and incubated for nine days at room temperature. The data obtained are contained in Table CXXXII.

TABLE CXXXII

Consumption of Dissolved Oxygen in Harbor Water from the Lower East River Incubated for 2, 7 and 9 Days at Room Temperature

Source of Sample	Date of Collection	Temp. Deg. C.	Specific Gravity	Aver. Temp. During Incubation Deg. C.	Dissolved Oxygen					
					C. C. per Litre					Per Cent. Lost in 9 ds.
					Initial	After Incubation for			Loss in 9 ds.	
						2 ds.	7 ds.	9 ds.		
East River at	1913									
Hell Gate...........	Aug. 23	21.7	1018.0	21.7	5.60	4.20	2.90	2.50	3.10	55
Queensboro Bridge...	Aug. 23	23.9	1018.5	21.7	5.29	4.74	3.16	2.76	2.53	48
Williamsburg Bridge.	Aug. 23	23.3	1019.0	21.7	5.45	4.67	3.20	2.30	3.15	58
Brooklyn Bridge.....	Aug. 23	23.3	1018.5	21.7	5.29	4.58	3.48	2.98	2.31	43
									Average	51

The data given in Table CXXXII show that the four samples of water collected from the East river on August 23, 1913, lost, on an average, 51 per cent. of their dissolved oxygen on incubation for 9 days at room temperature.

CONSUMPTION OF DISSOLVED OXYGEN BY WATER FROM VARIOUS POINTS IN THE HARBOR

Nine sets of samples, collected near the surface and near the bottom on flow and ebb tides, were taken at various points in the harbor during 1912 and 1913 and tested at once for dissolved oxygen.

Duplicate samples brought to the laboratory were incubated for 7 days at room temperature and then tested for dissolved oxygen. The data obtained are given in Tables CXXXIII to CXXXVII.

TABLE CXXXIII

DISSOLVED OXYGEN IN HARBOR WATER BEFORE AND AFTER INCUBATION—EAST RIVER AT BROOKLYN BRIDGE, MID-STREAM

Date	Surface			Current	Date	Bottom			Current
	C. C. per Litre of Water					C. C. per Litre of Water			
	As Collected	After Incubation	Lost			As Collected	After Incubation	Lost	
1912					1912				
Apr. 3	6.71	3.92	2.97	Flood	Apr. 3	6.71	3.78	2.79	Flood
	6.71	3.47	3.24	Ebb		6.43	3.11	3.32	Ebb
June 13	3.68	2.86	0.82	Flood	June 13	3.68	2.55	1.13	Flood
	3.88	2.76	1.12	Ebb		3.88	2.86	1.02	Ebb
July 11	2.60	0.80	1.80	Flood	July 11	2.60	0.80	1.80	Flood
	2.40	0.70	1.70	Ebb		2.40	2.40	0.70	Ebb
July 24	2.80	1.00	1.80	Flood	July 24	2.80	1.20	1.60	Flood
	2.50	0.60	1.90	Ebb		2.50	0.70	1.80	Ebb
1913					1913				
Jan. 9	6.00	4.60	1.40	Flood	Jan. 9	6.00	4.90	1.10	Flood
	5.60	4.80	0.80	Ebb		5.60	4.60	1.00	Ebb
Feb. 18	5.60	3.10	2.50	Flood	Feb. 18	5.60	3.00	2.40	Flood
	5.40	2.00	3.40	Ebb		5.40	3.00	2.40	Ebb
June 11	4.83	1.80	3.03	Flood	June 11	5.08	2.83	2.25	Flood
	2.49	0.00	2.49	Ebb		2.51	0.00	2.51	Ebb
July 25	2.60	0.70	1.90	Flood	July 25	2.45	1.35	1.10	Flood
	1.20	0.77	0.43	Ebb		1.35	0.33	1.02	Ebb
Sept. 19	2.30	1.58	0.72	Flood	Sept. 19	1.90	1.89	0.01	Flood
	2.00	0.40	1.60	Ebb		1.99	1.39	0.60	Ebb
Average	3.85	1.99	1.86		Average	3.83	2.26	1.58	

TABLE CXXXIV

DISSOLVED OXYGEN IN HARBOR WATER BEFORE AND AFTER INCUBATION—HUDSON RIVER, MID-STREAM, PIER A

Date	Surface			Current	Date	Bottom			Current
	C. C. per Litre of Water					C. C. per Litre of Water			
	As Collected	After Incubation	Lost			As Collected	After Incubation	Lost	
1912					1912				
Apr. 3	7.43	4.46	2.97	Flood	Apr. 3	6.80	4.32	2.48	Flood
	7.57	3.89	3.68	Ebb		7.57	3.78	3.79	Ebb
June 13	4.19	3.16	1.03	Flood	June 13	4.19	2.86	1.33	Flood
	4.49	3.16	1.33	Ebb		4.39	3.27	1.12	Ebb
July 11	3.00	0.80	2.20	Flood	July 11	——	——	——	Flood
	2.90	1.10	1.80	Ebb		2.80	0.60	1.20	Ebb
July 24	3.70	2.00	1.70	Flood	July 24	3.17	2.10	1.60	Flood
	3.10	2.00	1.10	Ebb		3.00	2.10	0.90	Ebb
1913					1913				
Jan. 9	6.20	5.00	1.20	Flood	Jan. 9	6.20	5.10	1.10	Flood
	5.70	4.40	1.30	Ebb		5.70	5.10	0.60	Ebb
Feb. 18	5.80	4.00	1.80	Flood	Feb. 18	5.90	4.00	1.90	Flood
	5.80	4.00	1.80	Ebb		5.80	3.40	2.40	Ebb
June 11	4.11	2.08	2.03	Flood	June 11	4.72	2.09	2.63	Flood
	3.77	1.85	1.92	Ebb		3.97	1.80	2.17	Ebb
July 25	2.88	1.38	1.50	Flood	July 25	2.51	1.05	1.46	Flood
	2.70	1.33	1.44	Ebb		2.54	0.49	1.05	Ebb
Sept. 19	2.70	0.66	2.04	Flood	Sept. 19	2.80	1.31	1.49	Flood
	3.20	2.79	0.41	Ebb		3.51	1.60	1.91	Ebb
Average	4.35	2.65	1.74		Average	4.44	2.64	1.71	

TABLE CXXXV

DISSOLVED OXYGEN IN HARBOR WATER BEFORE AND AFTER INCUBATION—ROBBINS REEF, NEAR BELL BUOY

Date	Surface			Current	Date	Bottom			Current
	C. C. per Litre of Water					C. C. per Litre of Water			
	As Collected	After Incubation	Lost			As Collected	After Incubation	Lost	
1912					1912				
Apr. 3	7.28	4.17	3.11	Flood	Apr. 3	7.00	4.60	2.40	Flood
	7.28	3.33	3.95	Ebb		6.86	3.24	3.62	Ebb
June 13	4.29	3.16	1.13	Flood	June 13	4.29	3.27	1.02	Flood
	4.19	3.37	0.82	Ebb		4.19	3.27	0.92	Ebb
July 11	3.50	1.00	2.50	Flood	July 11	3.50	1.00	2.50	Flood
	3.00	0.70	2.30	Ebb		3.10	0.80	2.30	Ebb
July 24	3.60	2.60	1.00	Flood	July 24	3.70	2.60	1.10	Flood
	2.90	2.00	0.90	Ebb		2.90	2.20	0.70	Ebb
1913					1913				
Jan. 9	6.30	4.90	1.40	Flood	Jan. 9	5.40	5.30	1.10	Flood
	6.00	4.80	1.20	Ebb		6.00	5.00	1.00	Ebb
Feb. 18	6.20	4.00	2.20	Flood	Feb. 18	6.20	4.00	2.20	Flood
	5.90	3.30	2.60	Ebb		6.00	3.40	2.60	Ebb
June 11	5.26	2.63	2.63	Flood	June 11	5.83	3.94	1.89	Flood
	4.37	1.88	2.49	Ebb		5.58	1.25	4.23	Ebb
July 25	3.80	2.37	1.43	Flood	July 25	4.35	2.76	1.59	Flood
	2.18	1.65	0.45	Ebb		2.86	1.25	1.61	Ebb
Sept. 19	4.00	3.22	0.78	Flood	Sept. 19	4.18	2.80	0.38	Flood
	3.60	3.41	0.19	Ebb		4.10	3.97	0.13	Ebb
Average	4.64	2.92	1.73		Average	4.78	3.03	1.68	

TABLE CXXXVI

Dissolved Oxygen in Harbor Water Before and After Incubation—Kill Van Kull, Mid-stream, Sailors Snug Harbor

Date	Surface			Current	Date	Bottom			Current
	C. C. per Litre of Water					C. C. per Litre of Water			
	As Collected	After Incubation	Lost			As Collected	After Incubation	Lost	
1912					1912				
Apr. 3	7.00	4.44	2.56	Flood	Apr. 3	6.86	4.60	2.26	Flood
	7.28	4.31	2.97	Ebb		7.00	4.06	2.94	Ebb
June 13	4.39	2.96	1.43	Flood	June 13	4.39	3.06	1.33	Flood
	4.29	3.27	1.02	Ebb		4.29	3.37	0.92	Ebb
July 11	3.20	1.00	2.20	Flood	July 11	3.20	0.90	2.30	Flood
	3.10	0.80	2.30	Ebb		3.10	0.80	2.30	Ebb
July 24	3.80	2.50	1.30	Flood	July 24	3.80	2.60	1.20	Flood
	3.40	2.60	0.80	Ebb		3.30	2.60	0.70	Ebb
1913					1913				
Jan. 9	6.10	4.90	1.20	Flood	Jan. 9	6.20	4.60	1.60	Flood
	6.00	4.60	1.40	Ebb		6.00	5.00	1.00	Ebb
Feb. 18	6.20	3.60	2.60	Flood	Feb. 18	6.30	4.20	2.10	Flood
	5.80	3.40	2.40	Ebb		5.80	3.00	2.80	Ebb
June 11	4.39	2.37	1.92	Flood	June 11	3.92	2.33	1.59	Flood
	4.61	2.92	1.69	Ebb		4.33	3.56	0.77	Ebb
July 25	3.60	1.30	2.30	Flood	July 25	3.25	1.02	2.23	Flood
	2.80	1.18	1.62	Ebb		3.65	2.18	1.47	Ebb
Sept. 19	2.70	2.09	0.61	Flood	Sept. 19	3.12	1.42	1.70	Flood
	3.10	1.30	1.80	Ebb		3.50	1.69	1.81	Ebb
Average	4.52	2.75	1.79		Average	4.56	2.83	1.72	

TABLE CXXXVII

Dissolved Oxygen in Harbor Water Before and After Incubation—Narrows, Mid-stream, Between Forts Lafayette and Wadsworth

Date	Surface			Current	Date	Bottom			Current
	C. C. per Litre of Water					C. C. per Litre of Water			
	As Collected	After Incubation	Lost			As Collected	After Incubation	Lost	
1912					1912				
Apr. 3	7.71	4.86	2.85	Flood	Apr. 3	7.57	4.87	2.70	Flood
	7.43	4.17	3.26	Ebb		7.14	4.06	3.08	Ebb
June 13	4.80	3.58	1.22	Flood	June 13	4.90	3.68	1.22	Flood
	4.29	3.47	0.82	Ebb		4.39	3.57	0.82	Ebb
July 11	3.90	1.80	2.10	Flood	July 11	4.00	1.80	2.20	Flood
	3.20	1.00	2.20	Ebb		3.30	1.00	2.20	Ebb
July 24	3.90	2.40	1.50	Flood	July 24	4.00	2.60	1.40	Flood
	3.40	2.20	1.20	Ebb		3.40	2.40	1.00	Ebb
1913					1913				
Jan. 9	6.80	5.10	1.70	Flood	Jan. 9	6.80	5.40	1.40	Flood
	6.10	5.10	1.00	Ebb		6.10	5.00	1.10	Ebb
Feb. 18	6.60	4.80	1.80	Flood	Feb. 18	6.70	4.80	1.90	Flood
	6.00	3.80	2.20	Ebb		6.10	4.00	2.20	Ebb
June 11	4.11	2.79	1.32	Flood	June 11	4.15	3.03	1.12	Flood
	5.66	3.36	2.30	Ebb		6.07	3.26	2.81	Ebb
July 25	3.10	2.70	0.40	Flood	July 25	4.05	2.86	2.19	Flood
	4.10	2.67	1.43	Ebb		5.25	3.71	1.54	Ebb
Sept. 19	3.40	2.09	1.31	Flood	Sept. 19	3.60	2.53	1.07	Flood
	4.60	4.57	.03	Ebb		5.12	4.13	0.99	Ebb
Average	4.95	3.37	1.59		Average	5.15	3.48	1.72	

Dissolved Oxygen in Harbor Water in Cold and in Warm Weather

Inspection of the records given in Tables CXXXIII to CXXXVII shows that the amount of oxygen dissolved in the harbor waters was much greater in winter than in summer. The figures given in the tables have been summarized for the purpose of illustrating this fact and the data are given in Table CXXXVIII.

TABLE CXXXVIII

Dissolved Oxygen in Harbor Water in Cold and in Warm Weather

Source of Samples	C. C. per Litre	
	Jan., Feb., April	June, July, Sept.
East river	5.81	2.77
Hudson river	6.37	3.40
Robbins Reef	6.79	3.87
Kill van Kull	6.37	3.55
Narrows	6.59	4.19
Total	31.93	17.78
Average	6.39	3.56

The data given in Table CXXXVIII show that the harbor water contained 2.83 c.c. more dissolved oxygen on the average in winter than in summer. This may have been due partly to the fact that cold water is capable of holding more oxygen than warm water. For instance, harbor water saturated with dissolved oxygen at 40° F. contains about 7.8 c.c., whereas harbor water saturated with dissolved oxygen at 72° F. contains only 5.4 c.c.

The differences in volume of oxygen dissolved in samples of harbor water collected in winter and summer may have been due partly to the fact that bacterial fermentation, upon which the decomposition of the organic matter depends, proceeds more rapidly in warm weather, and for that reason the oxygen is withdrawn from the water more rapidly.

Sewage, however, flows into the harbor at all seasons of the year and it is important to know whether, if digested, it will consume equal volumes of oxygen at all seasons. Data upon this point can be obtained by adding to the oxygen consumed by digestion in the river the dissolved oxygen consumed during incubation at room temperature.

The records of the volumes of oxygen dissolved in the 36 samples of harbor water, before and after incubation, which are printed in Tables CXXXIII to CXXXVII, have been averaged and are printed in Table CXXXIX, together with figures for the saturation, etc., in order to bring out the desired information.

TABLE CXXXIX

Volume of Dissolved Oxygen Consumed During Digestion of Sewage

	Period	
	Jan., Feb., April	June, July, Sept.
Temperature	40° F.	70° F.
Per cent. Sea Water	70	70
Dissolved Oxygen Required for Saturation	7.70 c.c.	5.50 c.c.
Found by Analysis at Time of Collection	6.39	3.56
Lost by Digestion in Harbor	1.31 c.c.	1.94 c.c.
Lost by Incubation for 7 Days at 70° F	2.18 c.c.	1.48 c.c.
Total Loss During Digestion	3.49 c.c.	3.42 c.c.

The actual volumes of oxygen consumed in the digestion of sewage in the harbor vary with changes of temperature and also with the volume absorbed by water from the air.

Data given elsewhere in reports of the Commission show that the rate at which waters absorb oxygen from the atmosphere vary with the amounts of oxygen which the waters contain already, and also with temperature and pressure according to the physical laws which govern volumes of gases. But this latter factor, together with variations produced by such physical agents as tidal currents, winds, moving ships, etc., may be left out of the present discussion because the actual effects produced are unknown and operate at all seasons of the year.

The data given in Table CXXXIX show that the volume of oxygen which the organic matter carried by harbor water will consume during digestion in cold weather is 3.49 c.c. per litre and in warm weather 3.42 c.c. Roughly speaking then, the volume of dissolved oxygen required for the digestion of sewage in the harbor water is approximately the same at all seasons of the year.

The data given in Tables CXXXIII to CXXXVII prove that the volumes of dissolved oxygen consumed by harbor waters during various seasons of the year vary with the locality from which the samples are taken. This fact is brought out in the following table:

TABLE CXL

*Volumes and Percentages of Dissolved Oxygen Contained by Harbor Water Before and After Incubation

Source of Sample	Dissolved Oxygen					
	C. C. per Litre Present		Loss	Per Cent. Present		Loss
	Before Incubation	After Incubation		Before Incubation	After Incubation	
East river at Brooklyn Bridge	3.84	2.12	1.72	100	55.2	44.8
Hudson river, off Pier A	4.39	2.65	1.75	100	60.3	39.7
Robbins Reef, near Bell buoy	4.71	2.98	1.72	100	63.2	36.8
Kill van Kull at Sailors Snug Harbor	4.55	2.79	1.75	100	61.4	38.6
Narrows, between Forts	5.04	3.42	1.62	100	67.3	32.7

*Averages of 39 sets of determinations.

The data given in Table CXL show that the samples of harbor water from all sources lost approximately equal volumes of dissolved oxygen during incubation. The samples from the East river, however, lost a larger percentage of the oxygen which they originally contained than samples from the Narrows. This fact indicates that the organic matter in the East river water was more unstable than that in the harbor water at the Narrows.

Dissolved Oxygen on Ebb and Flood Tides

The data in Tables CXXXIII to CXXXVII have been arranged with reference to the volumes of dissolved oxygen contained by ebb and flood tides. The data are given in Table CXLI.

TABLE CXLI

Dissolved Oxygen Contained by Harbor Waters on Ebb and Flood Tides

	Average Number of C. C. per Litre				
	East River, Brooklyn Bridge	Hudson River, Pier A	Robbins Reef, Bell Buoy	Kill van Kull, Sailors Snug Harbor	Narrows, between Forts
Ebb	3.57	4.36	4.50	4.47	5.09
Flood	4.11	4.24	4.93	4.62	5.00

The data given in Table CXLI show that the amount of dissolved oxygen contained by the harbor water did not differ much on the ebb and flood tides.

Dissolved Oxygen in Surface and Bottom Samples

The data contained in Tables CXXXIII to CXXXVII have been arranged with regard to the location of the samples for the purpose of comparing the oxygen contained by water lying near the surface with that at the bottom. The data are given in Table CXLII.

TABLE CXLII

Dissolved Oxygen Contained by Harbor Water Collected About One Foot Below the Surface and One Foot Above the Bottom

	Average Number of C. C. per Litre				
	East River, Brooklyn Bridge	Hudson River, Pier A	Robbins Reef, Bell Buoy	Kill van Kull, Sailors Snug Harbor	Narrows, between Forts
Top	3.65	4.40	4.64	4.57	4.95
Bottom	3.82	4.20	4.78	4.51	5.15

The data given in this table show that there was not much difference between the amounts of oxygen contained by the surface and bottom samples.

CONSUMPTION OF OXYGEN IN MIXTURES OF SEWAGE AND AERATED WATER DURING INCUBATION

As the sewage uses up part of the oxygen contained by the water, it is important to know whether the solid or liquid portion of the organic matter consumes the greater volume of oxygen. To get information on this point mixtures of aerated harbor, land and sea water were made with various percentages of raw, settled and filtered sewage. The volumes of dissolved oxygen contained by the mixtures were determined at the time when the mixtures were made and after incubation for various periods.

CONSUMPTION OF DISSOLVED OXYGEN IN MIXTURES OF HARBOR WATER WITH 20 PER CENT. OF RAW AND WITH 20 PER CENT. OF SETTLED SEWAGE

Sewage collected from the Delancey street sewer was carried to the laboratory, shaken thoroughly and divided into two parts. One portion after thorough agitation was mixed with aerated harbor water drawn from the East river at Pier 4 and the other portion was allowed to settle for two hours to free it from coarser particles of suspended matter. The supernatant liquor, siphoned from the upper portion of the sample, was shaken thoroughly and mixed with aerated harbor water. In each case 20 per cent. of sewage liquor was added to 80 per cent. of harbor water. Tests were made for dissolved oxygen at intervals. The data are given in Tables CXLIII, CXLIV and CXLV.

TABLE CXLIII

CONSUMPTION OF DISSOLVED OXYGEN ON INCUBATING MIXTURES CONTAINING 20 PER CENT. RAW SEWAGE AND 20 PER CENT. SETTLED SEWAGE WITH AERATED HARBOR WATER.

Date of Collection	Source of		Aver. Temp. Deg. F.	Dissolved Oxygen						
					Raw Sewage			Settled Sewage		
	Sewage	Harbor Water		After Standing	C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation	C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation
1913 Oct. 17	Delancey street, corner Pitt...	East river, Pier No. 4........	70	Initial	4.52	100	75	4.10	100	70
				2 hours	2.80	59	49	4.05	98	70
				4 hours	1.48	33	25	1.48	34	25
				5 hours	0.48	11	8	0.98	21	17
				6 hours	0.19	4	3	0.26	6	5
				7 hours	0.04	0.8	0.7	.00	0	0

TABLE CXLIV

Consumption of Dissolved Oxygen on Incubating Mixtures of 20 Per Cent. Raw Sewage and 20 Per Cent. Settled Sewage with Aerated Harbor Water

Date of Collection	Source of		Aver. Temp. Deg. F.	Dissolved Oxygen						
	Sewage	Harbor Water		After Standing	Raw Sewage			Settled Sewage		
					C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation	C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation
1913										
Oct. 21	Delancey street, corner Pitt...	East river, Pier No. 4........	60	Initial	6.41	100	101	6.51	100	103
			61	2 hours	5.28	80	82	6.51	100	103
			63	4 hours	4.38	66	71	5.23	80	85
			63	6 hours	3.73	58	60	4.82	74	78
			63	8 hours	2.09	32	33	3.45	53	55
			61	10 hours	0.18	2	3.2	1.12	17	16
			60	12 hours	0.00	0	0	——	——	——

TABLE CXLV

Consumption of Dissolved Oxygen on Incubating Mixtures of 20 Per Cent. Raw Sewage and 20 Per Cent. Settled Sewage with Aerated Harbor Water

Date of Collection	Source of		Aver. Temp. Deg. F.	Dissolved Oxygen						
	Sewage	Harbor Water		After Standing	Raw Sewage			Settled Sewage		
					C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation	C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation
1913										
Oct. 23	Delancey, near Pitt	East river, Pier No. 4.........	61	Initial	5.68	100	90	5.93	100	95
				2 hours	5.40	92	75	5.95	100	95
				4 hours	4.17	76	70	4.23	71	68
				6 hours	3.28	57	54	2.95	49	48
				12 hours	.05	0.7	0.6	0.51	10	8

The data given in Tables CXLIII, CXLIV and CXLV show that the raw and settled sewage consumed all the oxygen in the harbor water within 12 hours, and that the raw sewage used up the dissolved oxygen more rapidly than did settled sewage during the first two hours.

Consumption of Oxygen in Mixtures of Harbor Water with 5 Per Cent. of Raw and 5 Per Cent. of Settled Sewage

The large amount of organic matter introduced when 20 per cent. of sewage was added to the harbor water exhausted the oxygen rapidly. As the proportion of sewage to harbor water might not be as great as 20 per cent. in actual practice, tests were made using only 5 per cent. of sewage. The data obtained are given in Tables CXLVI and CXLVII.

TABLE CXLVI

Consumption of Dissolved Oxygen on Incubating Mixtures of 5 Per Cent. Raw Sewage and 5 Per Cent. Settled Sewage with Aerated Harbor Water

Date of Collection	Source of		Aver. Temp. Deg. F.	Dissolved Oxygen						
	Sewage	Harbor Water		After Standing	Raw Sewage			Settled Sewage		
					C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation	C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation
1913										
Oct. 28	Delancey street, corner of Pitt.	East river, Pier No. 4........	68	Initial	6.42	100	109	6.21	100	106
				6 hours	6.05	94	102	6.26	101	107
				21 hours	0.22	3	3	0.26	4	4
				24 hours	0.05	0	0	0.00	0	0

TABLE CXLVII

Consumption of Dissolved Oxygen on Incubating Mixtures of 5 Per Cent. Raw Sewage and 5 Per Cent. Settled Sewage with Aerated Harbor Water

Date of Collection	Source of		Aver. Temp. Deg. F.	Dissolved Oxygen						
	Sewage	Harbor Water		After Standing	Raw Sewage			Settled Sewage		
					C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation	C. C. per Litre	Per Cent. of Initial	Per Cent. Saturation
1913										
Oct. 30	Delancey street, corner of Pitt.	East river, Pier No. 4........	70	Initial	5.82	100	92	6.48	100	107
				6 hours	4.56	78	75	5.24	80	85
				12 hours	1.63	28	27	3.17	48	51
				21 hours	0.00	0	0	1.49	22	24
				24 hours	—	—	—	1.18	18	19
				28 hours	—	—	—	0.57	9	9

The data given in Tables CXLVI and CXLVII show that in the presence of 5 per cent. of raw sewage the organic matter consumed all the oxygen in the harbor water in 21 hours and that 5 per cent. of settled sewage consumed all the oxygen in about 28 hours.

CONSUMPTION IN MIXTURES OF LAND WATER WITH VARIOUS PERCENTAGES OF FILTERED SEWAGE

Sewage collected from the Delancey street sewer was carried to the Laboratory and passed through coarse filter paper to remove all of the suspended matter. Various quantities of this filtered sewage were then mixed with aerated land water and tests made at intervals for dissolved oxygen. The data obtained are given in Table CXLVIII.

TABLE CXLVIII

CONSUMPTION OF DISSOLVED OXYGEN ON INCUBATING MIXTURES OF 20 PER CENT., 10 PER CENT., 5 PER CENT. AND 3 PER CENT. OF FILTERED SEWAGE WITH AERATED LAND WATER.

Date of Collection	Composition of Sample	Aver. Temp. Deg. F.	Dissolved Oxygen C. C. per Litre		
			Initial	After Standing	
1913	Land Water, plus:			24 hours	5 days
Jan. 23	20 per cent. Filtered Sewage	80	4.60	0.10	0.00
Jan. 23	10 per cent. Filtered Sewage	80	5.10	0.30	0.00
Jan. 23	5 per cent. Filtered Sewage	80	6.20	2.60	0.50
Jan. 24	3 per cent. Filtered Sewage	80	5.80	4.80	1.70

The data given in Table CXLVIII show that in the presence of 10 per cent. or more of filtered sewage practically all the oxygen disappeared in 24 hours. On the other hand, land water mixed with 5 per cent. of filtered sewage lost only 60 per cent. and 3 per cent. of filtered sewage lost only 17 per cent. of dissolved oxygen in 24 hours. Almost all the oxygen disappeared from the 5 per cent. mixture in five days, but the 3 per cent. mixture still contained about 30 per cent. of oxygen at the end of this period.

CONSUMPTION IN MIXTURES OF SEA WATER WITH VARIOUS PERCENTAGES OF FILTERED SEWAGE

Samples of the filtered sewage described in the preceding tables were mixed in various percentages with aerated sea water, collected off Sandy Hook, and tested for dissolved oxygen after different periods of incubation. The data obtained are given in Table CXLIX.

TABLE CXLIX

CONSUMPTION OF DISSOLVED OXYGEN ON INCUBATING MIXTURES OF 50 PER CENT., 20 PER CENT., 10 PER CENT., 5 PER CENT. AND 3 PER CENT. OF FILTERED SEWAGE WITH AERATED SEA WATER.

Date of Collection	Composition of Sample	Aver. Temp. Deg. F.	Dissolved Oxygen C. C. per Litre		
			Initial	After Standing	
1913	Sea Water, plus			24 hours	5 days
Jan. 23	50 per cent. Filtered Sewage	80	4.36	0.00	0.00
Jan. 23	20 per cent. Filtered Sewage	80	4.00	0.10	0.00
Jan. 23	10 per cent. Filtered Sewage	80	5.00	0.50	0.00
Jan. 23	5 per cent. Filtered Sewage	80	5.80	2.40	0.60
Jan. 23	3 per cent. Filtered Sewage	80	5.50	4.50	0.60

The data given in Table CXLIX show that practically all the oxygen disappeared within 24 hours in mixtures of 10 per cent. or more of filtered sewage and aerated sea water. A mixture of sea water with 5 per cent of filtered sewage lost 60 per cent., and a mixture of sea water with 3 per cent. of filtered sewage lost 18 per cent. of dissolved oxygen in 24 hours. By the end of 5 days the oxygen had nearly disappeared.

CONSUMPTION IN MIXTURES OF FILTERED SEWAGE AND WATER CONTAINING VARIOUS INITIAL PERCENTAGES OF OXYGEN

Owing to the fact that oxygen exists in varying amounts in the harbor water, mixtures of land water, land and sea water, and sea water with filtered sewage were charged by aeration with oxygen to different percentages of saturation.

The samples were incubated at about 80° F. and tested for oxygen at the start, after 24 hours and after 5 days. The data obtained are given in Tables CL, CLI and CLII.

TABLE CL

CONSUMPTION OF OXYGEN ON INCUBATING MIXTURES OF 20 PER CENT., 10 PER CENT., 5 PER CENT. AND 3 PER CENT. OF FILTERED SEWAGE WITH AERATED LAND WATER CONTAINING VARIOUS AMOUNTS OF OXYGEN.

Composition of Sample	Aver. Temp. Deg. F.	Dissolved Oxygen C. C. per Litre		
		Initial	After Standing for	
			24 hours	5 days
Land Water, plus:				
20 per cent. Filtered Sewage	80	4.60	0.10	0.00
		1.60	0.10	0.00
		0.40	0.00	0.00
10 per cent. Filtered Sewage	80	5.10	0.30	0.00
		2.00	0.00	0.00
		0.80	0.00	0.00
5 per cent. Filtered Sewage	80	6.20	2.60	0.50
		4.90	0.70	0.00
		1.90	0.00	0.00
3 per cent. Filtered Sewage	80	5.80	4.80	1.70
		3.90	2.40	0.30
		0.90	0.60	0.00

TABLE CLI

CONSUMPTION OF OXYGEN ON INCUBATING 10 PER CENT. OF FILTERED SEWAGE ADDED TO A MIXTURE OF 60 PER CENT. SEA WATER WITH 40 PER CENT. OF LAND WATER CONTAINING VARIOUS AMOUNTS OF DISSOLVED OXYGEN.

Composition of Sample	Aver. Temp. Deg. F.	Dissolved Oxygen C. C. per Litre		
		Initial	After Standing for	
			6 hours	24 hours
60 per cent. Sea Water, 40 per cent. Land Water, plus:				
10 per cent. Filtered Sewage	80	5.50	4.50	0.60
		3.20	2.70	0.20
		1.50	0.90	0.20

TABLE CLII

CONSUMPTION OF OXYGEN ON INCUBATING MIXTURES OF 20 PER CENT., 10 PER CENT., 5 PER CENT. AND 3 PER CENT. OF FILTERED SEWAGE WITH AERATED SEA WATER CONTAINING VARIOUS AMOUNTS OF OXYGEN.

Composition of Sample	Aver. Temp. Deg. F.	Dissolved Oxygen C. C. per Litre	
		Initial	After Standing for
Sea Water, plus:			24 hours
20 per cent. Filtered Sewage	80	4.00	0.10
		2.40	0.00
		0.60	0.00
10 per cent. Filtered Sewage	80	5.00	0.50
		3.00	0.40
		1.60	0.40
5 per cent. Filtered Sewage	80	5.80	2.40
		4.00	0.80
		1.90	0.40
3 per cent. Filtered Sewage	80	5.50	4.50
		3.60	2.70
		1.30	0.80

The data given in Tables CL, CLI and CLII show that when filtered sewage, mixed with land or sea water containing various amounts of oxygen, is incubated the loss of oxygen is proportionally much greater when the water contains the most oxygen.

OXYGEN CONSUMED BY SLUDGE

The beds of sludge formed in the harbor by deposits of suspended matter in sewage undergo fermentation and exhaust the oxygen from the overlying harbor water. In order to determine how rapidly the consumption of oxygen proceeds sludge, dredged from the slip at Pier 4, East river, on July 17, 1913, was placed in a bottle.

Aerated water, collected on the same day off South Ferry, was poured into the bottle, care being taken to disturb the sludge as little as possible. The sample was incubated for 24 hours at an average temperature of 75° F. and tested for oxygen. The data obtained are given in Table CLIII.

TABLE CLIII

Consumption of Oxygen by Harbor Water During Incubation Over Sludge Dredged From the Harbor Bottom

Sample of Harbor Water	Aver. Temp. Deg. F.	Dissolved Oxygen C. C. per Litre	
		Initial	After Standing for
			24 hours
Over 10 per cent. of Harbor Sludge	80	4.18	0.10

The data given in Table CLIII show that the oxygen contained in the harbor water was exhausted by the harbor sludge in 24 hours.

Conclusions

The data presented in the preceding tables in regard to the changes which take place in harbor water during incubation show that the dissolved oxygen was always largely reduced.

Samples collected in winter lose from 4 to 5 c.c. of oxygen, while in summer they lose only 1 or 2 c.c. This fact indicates that the low temperatures of winter retard the bacterial decomposition of sewage entering the harbor, thereby throwing an extra burden in summer upon the digestive capacity of the harbor water. This heavy burden is placed upon the water at a time when the available supply of dissolved oxygen is reduced on account of the prevailing high temperature of the water.

Compounds containing nitrogen in the harbor water also undergo marked changes during incubation, albuminoid ammonia and nitrates decrease, whereas free ammonia and nitrites increase. This indicates clearly that the waters receiving sewage from the metropolitan district contain quantities of undigested organic matter.

Unpolluted sea water loses very little oxygen during incubation and land water from the public water supply loses comparatively little. But when more than 10 per cent. of either raw or settled sewage is mixed with sea, harbor or land water and incubated, even though saturated with oxygen, all the oxygen will disappear in from 6 to 12 hours. Five per cent. of either raw or settled sewage exhausts the oxygen from aerated waters in from 20 to 24 hours, but 3 per cent. does not exhaust the oxygen for 5 days.

Sewage from which the gross solids have been removed by sedimentation for two hours exhausts oxygen a little less rapidly than raw sewage during the first few hours of incubation. Either raw or settled sewage, however, makes a continuous drain for many hours upon the oxygen which is dissolved in harbor water.

The volume of oxygen required to oxidize the sewage entering the harbor may be estimated from data obtained by incubating 5 per cent. of sewage in water collected from the East river when 6 c.c. of oxygen were consumed per litre, or 1,428 lbs. per million gallons of raw sewage. Assuming that the metropolitan district will produce 770,000,000 gallons of sewage a day in 1915, the data show that 527 tons of oxygen will be required to oxidize this sewage.

Sludge dredged from the bottom of slips along the East river absorbed oxygen rapidly, especially when stirred up. Therefore when passing boats churn up the layers of sewage sludge deposited in slips or on the harbor bottom the fermenting organic matter exhausts the oxygen from a large volume of the surrounding water.

SECTION V

THE ABSORPTION OF DISSOLVED OXYGEN BY LAND WATER AND SEA WATER AND MIXTURES THEREOF

Samples of land water and sea water were boiled 30 minutes and siphoned while still boiling into wide-mouthed jars holding one quart each. These jars were 9 inches high and 3½ inches in diameter and had mouths 1¾ inches in diameter. Each was fitted with a No. 10 rubber stopper with perforations through which glass tubing extended. The boiling water was siphoned into each jar through a glass tube, and carbonic acid was drawn in by contraction of the water as it cooled from a reservoir attached to the other tube. The CO_2 reservoir was protected from contamination with oxygen by connecting the inlet to a train of wash bottles charged with a mixture of caustic soda and pyrogallic acid.

When the jars were thoroughly cooled the stoppers were removed from all except one, and the contents exposed to the air.

The water in the unopened jar was siphoned into a Soper oxygen testing bottle and analyzed to determine how much oxygen was contained by the water in the jars at the start. At intervals the contents of the open jars were siphoned into oxygen bottles and tested.

The contents of the jars were not agitated during the period when the samples were absorbing oxygen.

Absorption by Land Water

The results obtained for land water are shown in Tables CLIV to CLVII, inclusive:

TABLE CLIV

Dissolved Oxygen Absorbed by Land Water

Time Exposed to Air	Specific Gravity	Temp. Deg. F.	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain per hour since last test	Gain per 24 hours
Initial	1000	68	0.14	2	——	——
1 hour	1000	68	0.86	13	11%	——
2 hours	1000	68	1.43	22	9%	——
3 hours	1000	68	1.86	29	7%	——
4 hours	1000	68	2.14	33	4%	——
5 hours	1000	68	2.43	37	4%	——
6 hours	1000	68	2.57	40	3%	——
7 hours	1000	68	2.71	42	2%	——
8 hours	1000	68	2.86	44	2%	——
24 hours	1000	68	3.71	57	0.8%	55%

TABLE CLV

DISSOLVED OXYGEN ABSORBED BY LAND WATER

Time Exposed to Air	Specific Gravity	Temp. Deg. F.	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain Since Exposed	Gain per 24 Hours
Initial	1000	70	0.28	4	0.0%	0.0%
24 hours	1000	70	3.57	56	52.0%	52.0%
2 days	1000	70	4.43	70	66.0%	14.0%
3 days	1000	70	5.14	80	76.0%	10.0%
4 days	1000	70	5.71	89	85.0%	9.0%
5 days	1000	70	5.86	92	88.0%	3.0%
6 days	1000	70	6.00	94	90.0%	2.0%
7 days	1000	70	6.14	96	92.0%	2.0%

TABLE CLVI

DISSOLVED OXYGEN ABSORBED BY LAND WATER

Time Exposed to Air	Temperature Deg. F.	Specific Gravity	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain per Hour since last test	Gain per 24 Hours
Initial	70	1000	0.28	4	——	——
1 hour	70	1000	1.00	16	12%	——
2 hours	70	1000	1.57	25	9%	——
3 hours	70	1000	2.00	31	6%	——
4 hours	70	1000	2.28	35	4%	——
5 hours	70	1000	2.57	40	5%	——
6 hours	70	1000	2.71	43	3%	——
7 hours	70	1000	2.85	45	2%	——
8 hours	70	1000	3.00	47	2%	——
24 hours	70	1000	3.71	58	0.70%	54%
2 days	70	1000	4.43	70	0.50%	12%
3 days	70	1000	5.14	80	0.42%	10%
4 days	70	1000	5.57	87	0.30%	7%
6 days	70	1000	6.00	94	0.15%	3.5%
7 days	70	1000	6.14	96	0.08%	2.0%
10 days	70	1000	6.76	100	0.06%	1.3%

TABLE CLVII

DISSOLVED OXYGEN ABSORBED BY LAND WATER

Time Exposed to Air	Temperature Deg. F.	Specific Gravity	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain per Hour since last test	Gain per 24 Hours
Initial	65	1000	0.27	4	——	——
1 hour	65	1000	0.92	14	10%	——
2 hours	65	1000	1.53	23	9%	——
3 hours	65	1000	1.90	30	7%	——
4 hours	65	1000	2.29	34	4%	——
5 hours	65	1000	2.57	38	4%	——
6 hours	65	1000	2.70	40	2%	——
7 hours	65	1000	2.84	42	2%	——
8 hours	65	1000	2.98	44	2%	——
16 hours	65	1000	3.51	52	1%	——
24 hours	65	1000	3.78	58	0.75%	54%
2 days	65	1000	4.73	70	0.50%	12%
3 days	65	1000	5.41	80	0.42%	10%
4 days	65	1000	6.22	92	0.25%	6%
6 days	65	1000	6.35	94	0.08%	2%
7 days	65	1000	6.49	96	0.08%	2%
10 days	65	1000	6.62	98	0.08%	0.67%

Tables CLIV to CLVII show that a rapid absorption took place for the first few hours, the rate diminishing with each succeeding hour. The rate was much more rapid for the first day than for the days following, decreasing with each succeeeding day.

Absorption by Sea Water

The results obtained for sea water are shown in Tables CLVIII to CLXI, inclusive:

TABLE CLVIII

Oxygen Absorbed by Sea Water

Time Exposed to Air	Specific Gravity	Temperature Deg. F.	Dissolved Oxygen			
			C. C. per iter	Per Cent. Saturation	Gain per Hour since last test	Gain per 24 Hours
Initial	1020	68	0.14	2	—	—
1 hour	1020	68	0.71	13	11%	—
2 hours	1020	68	1.28	23	10%	—
3 hours	1020	68	1.71	30	7%	—
4 hours	1020	68	2.00	36	6%	—
5 hours	1020.5	68	2.28	41	5%	—
6 hours	1020.5	68	2.57	46	5%	—
7 hours	1020.5	68	2.71	48	2%	—
8 hours	1020.5	68	2.86	51	3%	—
24 hours	1021	68	3.43	61	0.62%	59%

TABLE CLIX

Oxygen Absorbed by Sea Water

Time Exposed to Air	Specific Gravity	Temperature Deg. F.	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain Since Exposed	Gain per 24 Hours
Initial	1022	70	0.28	4	—	—
24 hours	1023	70	3.43	65	61%	61%
2 days	1023	70	4.28	81	77%	16%
3 days	1023	70	4.71	90	86%	9%
4 days	1023.5	70	5.00	94	90%	4%
5 days	1024	70	5.14	97	93%	3%
6 days	1024	70	5.14	97	93%	0%
7 days	1024	70	5.29	99	95%	2%

TABLE CLX

OXYGEN ABSORBED BY SEA WATER

Time Exposed to Air	Temperature Deg. F.	*Specific Gravity	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain per Hour since last test	Gain per 24 Hours
Initial	65	1023.5	0.14	3	——	——
1 hour	65	1023.5	0.71	13	10%	——
2 hours	65	1023.5	1.25	22	9%	——
3 hours	65	1024.0	1.67	30	8%	——
4 hours	65	1024.0	1.95	35	5%	——
5 hours	65	1024.0	2.22	40	5%	——
6 hours	65	1024.5	2.50	45	5%	——
7 hours	65	1025.0	2.64	48	3%	——
8 hours	65	1025.0	2.78	50	2%	——
16 hours	65	1025.5	3.34	60	1.25%	——
24 hours	65	1025.5	3.61	65	0.63%	62%
2 days	65	1025.5	4.45	81	0.67%	16%
3 days	65	1025.5	5.00	91	0.42%	10%
5 days	65	1026.0	5.28	96	0.10%	2.5%
6 days	65	1026.0	5.42	98	0.08%	2.0%
7 days	65	1026.0	5.42	98	0.00%	0.0%
10 days	65	1026.0	5.55	100	0.03%	0.7%

*The specific gravity of the sea water was increased by evaporation during the period of boiling.

TABLE CLXI

OXYGEN ABSORBED BY SEA WATER

Time Exposed to Air	Temperature Deg. F.	*Specific Gravity	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain per Hour since last test	Gain per 24 hours
Initial	65	1027.5	0.13	2	——	——
1 hour	65	1027.5	0.68	13	11%	——
2 hours	65	1027.5	1.22	23	10%	——
3 hours	65	1027.5	1.62	30	7%	——
4 hours	65	1027.5	1.89	35	5%	——
5 hours	65	1028.0	2.17	40	5%	——
6 hours	65	1028.0	2.30	43	3%	——
7 hours	65	1028.0	2.43	45	2%	——
8 hours	65	1028.0	2.57	48	3%	——
16 hours	65	1028.0	2.98	55	0.87%	——
24 hours	65	1028.0	3.38	62	0.87%	60%
2 days	65	1028.0	4.19	78	0.67%	16%
3 days	65	1028.0	4.73	88	0.42%	10%
4 days	65	1028.0	5.00	93	0.21%	5%
5 days	65	1028.0	5.14	95	0.08%	2%
6 days	65	1028.5	5.27	97	0.08%	2%
7 days	67	1028.5	5.27	99	0.08%	2%

*The specific gravity of the sea water was increased by evaporation during the period of boiling.

Tables CLVIII to CLXI show the same general behavior of sea water as shown for land water in Tables CLIV to CLVII. The rate of absorption was rapid upon first exposure to the air and diminished with time, until near the point of saturation, when the absorption proceeded very slowly.

By a comparison of the results obtained with land water and sea water, it is seen that the latter recovers its oxygen at a slightly more rapid rate than the former. The difference was first apparent at about the third hour after exposure to the air, and amounted to 4 or 5 per cent. at the end of 24 hours.

Absorption by Mixtures of Land and Sea Water

The results obtained in experiments with mixtures are shown in Tables CLXII and CLXIII.

TABLE CLXII

Oxygen Absorbed by Land Water Mixed with Sea Water

Time Exposed to Air	Specific Gravity	Temperature Deg. F.	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain per Hour since last test	Gain per 24 Hours
Initial	1006.5	68	0.28	4	——	——
1 hour	1006.5	68	0.86	14	10%	——
2 hours	1006.5	68	1.43	23	9%	——
3 hours	1006.5	68	1.86	30	7%	——
4 hours	1006.5	68	2.14	34	4%	——
5 hours	1006.5	68	2.43	39	5%	——
6 hours	1006.5	68	2.63	42	3%	——
7 hours	1006.5	68	2.86	46	4%	——
8 hours	1006.5	68	3.00	48	2%	——
24 hours	1007.0	68	3.86	62	0.87%	58%

TABLE CLXIII

Oxygen Absorbed by Land Water Mixed with Sea Water

Time Exposed to Air	Specific Gravity	Temperature Deg. F.	Dissolved Oxygen			
			C. C. per Liter	Per Cent. Saturation	Gain per Hour since last test	Gain per 24 Hours
Initial	1011.5	70	0.28	5	——	——
24 hours	1012.0	70	3.43	60	55%	55%
2 days	1012.5	70	4.28	74	69%	14%
3 days	1012.5	70	4.86	84	79%	10%
4 days	1012.5	70	5.28	91	86%	7%
5 days	1012.5	70	5.43	94	89%	3%
6 days	1012.5	70	5.57	96	91%	2%
7 days	1012.5	70	5.63	97	92%	1%

Tables CLXII and CLXIII show that the mixture of land and sea water behaved in the same general way as either land or sea water, as regards the rate of absorption. The rate was somewhat less than that of undiluted sea water, and slightly greater than that of land water.

CONCLUSIONS

1. Land or sea water, from which the dissolved oxygen has been exhausted will absorb oxygen rapidly from the atmosphere if exposed to the air in an open vessel.

2. The rate of absorption is especially rapid during the first hour, but decreases as the degree of saturation increases, until the saturation figure is approached, when the rate declines to less than 1 per cent. per 24 hours. Thus 10 per cent. of the saturation value was taken up in the first hour, over 50 per cent. in the first day, and seven to ten days were required for saturation.

3. The rate of absorption was found to be rather more rapid in sea than in land water, figured in terms of the per cent. of saturation. The gain for the first day was about 8 per cent. greater in sea water than in land water.

4. A mixture of land and sea water showed the same general characteristics as to reabsorption of oxygen as were possessed by the ingredients separately. The rate of absorption lay between the rates for unmixed land and sea water.

5. The rate of absorption was very uniform for samples of a like character.

SECTION VI

CHEMICAL ANALYSES OF THE HARBOR WATER

INTRODUCTION

Samples of water collected from various parts of the harbor were analyzed for free and albuminoid ammonia, nitrites, nitrates and oxygen between February 27, 1912, and June 11, 1913, and the results are recorded in the following tables. In most cases duplicate samples were incubated and the condition of the water before and after incubation is here presented.

The samples were incubated for 7 days at the temperature and in the diffused light of the laboratory. Tests for nitrates and nitrites were made from the original samples on the day when they were collected and from the incubated samples at the end of a week. Some tests for free and albuminoid ammonia were made on the day of collection and some on the following day, that part of the sample which was not at once analyzed being preserved by means of chloroform.

TABLE CLXIV

Section No.	Location	Date of Collection	Pages
1	East river, midstream, Brooklyn Bridge	Feb. 27, 1912, to June 11, 1913	746
2	Hudson river, midstream, off Pier A	Feb. 27, 1912, to June 11, 1913	748
3	Robbins Reef, near bell buoy	Feb. 27, 1912, to June 11, 1913	750
4	Kill van Kull, midstream, off Sailors Snug Harbor	Mar. 4, 1912, to June 11, 1913	753
5	Narrows, between Forts Lafayette and Wadsworth	Feb. 27, 1912, to June 11, 1913	755

TABLE CLXIV

1—EAST RIVER, MIDSTREAM, BROOKLYN BRIDGE

Latitude 40° 42′ 20″. Longitude 73° 59′ 48″.

Sample No.	Date 1912	Hour A. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
1	Feb. 27	10.30	1	Slack low water	Before	2.2	6.57	80	0.548	0.102	0.001	0.189
2		10.40	30	Slack low water	Before	3.3	6.57	80	0.442	0.198	0.001	0.149
9	Mar. 4	10.30	1	Ebb	Before	1.7	6.57	79	0.236	0.284	0.001	0.109
10		10.35	30	Ebb	Before	2.2	6.57	80	0.272	0.324	0.001	0.139
19	Mar. 5	6.05	1	Flood	Before	0.6	6.86	80	0.316	0.240	0.001	0.179
20		6.10	30	Flood	Before	1.1	6.86	80	0.240	0.192	0.001	0.139
29	Mar. 14	11.15	1	Ebb	Before	4.4	6.43	80	0.400	0.324	0.001	0.239
29A		11.15	1	Ebb	After	21.1	2.28	40	—	0.468	0.002	—
					Difference	....	−4.15	−40	—	+0.144	+0.001	—
30	Mar. 14	11.20	30	Ebb	Before	4.4	6.43	80	0.408	0.348	0.001	0.259
30A		11.20	30	Ebb	After	21.1	2.10	37	—	0.524	0.003	—
					Difference	....	−4.33	−43	—	+0.176	+0.002	—
39	April 3	8.50	1	Flood	Before	6.1	6.71	82	0.244	0.168	0.001	0.149
39A		8.50	1	Flood	After	18.3	3.92	61	0.192	0.240	0.001	0.149
					Difference	....	−2.79	−21	−0.052	+0.072	0.000	0.000
40	April 3	9.00	30	Flood	Before	6.1	6.57	81	0.256	0.148	0.001	0.109
40A		9.00	30	Flood	After	18.3	3.78	60	0.168	0.220	0.001	0.129
					Difference	....	−2.79	−21	−0.088	+0.072	0.000	+0.020
		P. M.										
57	April 3	5.50	1	Ebb	Before	6.1	6.71	82	0.256	0.160	0.001	0.199
57A		5.50	1	Ebb	After	18.3	3.47	53	0.184	0.212	0.001	0.089
					Difference	....	−3.24	−29	−0.072	+0.052	0.000	−0.110
58	April 3	6.00	30	Ebb	Before	6.1	6.43	80	0.292	0.152	0.001	0.149
58A		6.00	30	Ebb	After	18.3	3.11	49	0.216	0.200	0.002	0.158
					Difference	....	−3.32	−31	−0.076	+0.048	+0.001	+0.009
		A. M.										
61	June 13	10.10	1	Ebb	Before	17.2	3.88	65	0.340	0.160	0.002	0.028
61A		10.10	1	Ebb	After	21.1	2.76	48	0.272	0.144	0.005	0.045
					Difference	....	−1.12	−17	−0.068	−0.016	+0.003	+0.017
62	June 13	10.15	30	Ebb	Before	16.7	3.88	64	0.284	0.144	0.002	0.038
62A		10.15	30	Ebb	After	21.1	2.86	51	0.208	0.284	0.003	0.037
					Difference	....	−1.02	−13	−0.076	+0.140	+0.001	−0.001
		P. M.										
79	June 13	4.30	1	Flood	Before	17.2	3.68	60	0.172	0.156	0.002	0.058
79A		4.30	1	Flood	After	21.1	2.86	50	0.248	0.188	0.007	0.073
					Difference	....	−0.82	−10	+0.076	+0.032	+0.005	+0.015
		A. M.										
80	June 13	4.35	30	Flood	Before	16.7	3.68	61	0.204	0.108	0.002	0.078
80A		4.35	30	Flood	After	21.1	2.55	45	0.160	0.356	0.008	0.052
					Difference	....	−1.13	−16	−0.044	+0.248	+0.006	−0.026
81	July 11	9.00	1	Ebb	Before	23.6	2.40	46	0.312	0.380	0.003	0.087
81A		9.00	1	Ebb	After	24.4	0.70	13	0.196	0.608	0.056	0.013
					Difference	....	−1.70	−33	−0.116	+0.228	+0.053	−0.074
82	July 11	9.10	30	Ebb	Before	23.6	2.40	46	0.284	0.408	0.003	0.097
82A		9.10	30	Ebb	After	24.4	0.70	13	0.212	0.624	0.000	0.020
					Difference	....	−1.70	−33	−0.072	+0.216	0.003	0.077

TABLE CLXIV—Continued

1—EAST RIVER, MIDSTREAM, BROOKLYN BRIDGE—Continued

Sample No.	Date 1912	Hour P. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
99	July 11	3.30	1	Flood	Before	23.9	2.60	50	0.272	0.452	0.003	0.087
99A		3.30	1	Flood	After	24.4	0.80	15	0.212	0.560	0.056	0.000
					Difference	....	−1.80	−35	−0.060	+0.108	+0.053	−0.087
100	July 11	3.35	30	Flood	Before	23.9	2.60	50	0.212	0.456	0.003	0.057
100A		3.35	30	Flood	After	24.4	0.80	15	0.180	0.432	0.153	0.037
					Difference	....	−1.80	−35	−0.032	−0.024	+0.150	−0.020
101	July 24	A. M. 9.30	1	Ebb	Before	21.7	2.50	46	0.328	0.548	0.070	0.060
101A		9.30	1	Ebb	After	23.9	0.60	11	0.160	0.608	0.072	0.038
					Difference	....	−1.90	−35	−0.168	+0.060	+0.002	−0.022
102	July 24	9.35	30	Ebb	Before	21.7	2.50	46	0.200	0.520	0.066	0.044
102A		9.35	30	Ebb	After	23.9	0.70	13	0.116	0.536	0.072	0.028
					Difference	....	−1.80	−33	−0.084	+0.016	+0.006	−0.016
119	July 24	P. M. 3.40	1	Flood	Before	21.7	2.80	50	0.160	0.456	0.080	0.000
119A		3.40	1	Flood	After	23.9	1.00	19	0.108	0.540	0.112	0.000
					Difference	....	−1.80	−31	−0.052	+0.084	+0.032	0.000
120	July 24	3.45	30	Flood	Before	21.1	2.80	51	0.200	0.460	0.078	0.032
120A		3.45	30	Flood	After	23.9	1.20	23	0.092	0.492	0.120	0.000
					Difference	....	−1.60	−28	−0.108	+0.032	+0.042	−0.032
313	1913 Jan. 9	A. M. 7.45	1	Flood	Before	2.8	6.00	68	0.204	0.168	0.016	0.144
313A		7.45	1	Flood	After	26.7	4.60	71	0.156	0.260	0.020	0.110
					Difference	....	−1.40	+3	−0.048	+0.092	+0.004	−0.034
323	Jan. 9	11.20	1	Ebb	Before	3.3	5.60	65	0.144	0.156	0.020	0.140
323A		11.20	1	Ebb	After	26.7	4.80	86	0.096	0.164	0.016	0.144
					Difference	....	−0.80	+21	−0.048	+0.008	−0.004	+0.004
333	Feb. 18	10.00	1	Ebb	Before	1.7	5.40	62	0.304	0.312	0.036	0.114
333A		10.00	1	Ebb	After	1.7	2.00	38	0.192	0.440	0.042	0.048
					Difference	....	−3.40	−24	−0.112	+0.128	+0.006	−0.066
334	Feb. 18	10.05	30	Ebb	Before	1.7	5.40	62	0.200	0.208	0.030	0.140
334A		10.05	30	Ebb	After	1.7	3.00	57	0.168	0.320	0.034	0.126
					Difference	....	−2.40	−5	−0.032	+0.112	+0.004	−0.014
351	Feb. 18	P. M. 5.10	1	Flood	Before	1.7	5.60	64	0.204	0.192	0.024	0.166
351A		5.10	1	Flood	After	21.1	3.10	55	0.092	0.244	0.024	0.166
					Difference	....	−2.50	−9	−0.112	+0.052	0.000	0.000
352	Feb. 18	5.15	30	Flood	Before	1.7	5.70	65	0.160	0.204	0.024	0.286
352A		5.15	30	Flood	After	21.1	3.40	60	0.148	0.296	0.026	0.214
					Difference	....	−2.30	−5	−0.012	+0.092	+0.002	−0.072
397	May 29	3.05	1	Flood	Before	15.3	4.70	72	0.108	0.252	0.034	0.056
397A		3.05	1	Flood	After	21.6	3.39	59	0.116	0.352	0.042	0.088
					Difference	....	−1.31	−13	+0.008	+0.100	+0.008	+0.032
399	May 29	3.30	30	Flood	Before	15.0	2.90	45	0.120	0.272	0.029	0.021
399A		3.30	30	Flood	After	21.6	2.31	40	0.120	0.392	0.040	0.040
					Difference	....	−0.59	−5	−0.000	+0.120	+0.011	+0.019
412	June 11	A. M. 9.05	1	Ebb	Before	16.5	2.49	40	0.256	0.460	0.044	0.096
412A		9.05	1	Ebb	After	16.7	0.00	0	0.096	0.384	0.050	0.060
					Difference	....	−2.49	−40	−0.160	−0.076	+0.006	−0.036

TABLE CLXIV—Continued

1—EAST RIVER, MIDSTREAM, BROOKLYN BRIDGE—Continued

Sample No.	Date 1913	Hour A. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
414	June 11	9.25	30	Ebb	Before	16.5	2.51	41	0.268	0.484	0.044	0.076
414A		9.25	30	Ebb	After	16.7	0.00	0	0.104	0.360	0.076	0.074
					Difference	....	−2.51	−41	−0.164	−0.124	+0.032	−0.002
		P. M.										
427	June 11	1.05	1	Flood	Before	18.4	4.83	85	0.188	0.316	0.040	0.120
427A		1.05	1	Flood	After	18.4	1.80	30	0.192	0.604	0.054	0.116
					Difference	....	−3.03	−55	+0.004	+0.288	+0.014	−0.004
429	June 11	1.25	30	Flood	Before	17.8	5.08	84	0.184	0.316	0.040	0.090
429A		1.25	30	Flood	After	17.8	2.83	47	0.192	0.652	0.130	0.040
					Difference	....	−2.25	−37	+0.008	+0.336	+0.090	−0.050

2—HUDSON RIVER, MIDSTREAM, OFF PIER A

Latitude 40° 42′ 19″. Longitude 74° 01′ 34″.

	1912	A. M.										
3	Feb. 27	11.30	1	Ebb	Before	2.8	6.57	80	0.446	0.426	0.001	0.199
4		11.40	30	Ebb	Before	2.8	6.57	80	0.438	0.196	0.001	0.209
11	Mar. 4	11.00	1	Ebb	Before	1.1	6.86	81	0.192	0.304	0.001	0.139
12		11.05	30	Ebb	Before	1.7	6.86	82	0.232	0.300	0.001	0.119
21	Mar. 5	6.25	1	Flood	Before	0.6	7.00	81	0.196	0.216	0.001	0.239
22		6.30	30	Flood	Before	1.1	7.00	82	0.196	0.216	0.001	0.189
31	Mar. 14	11.50	1	Ebb	Before	3.3	6.86	76	0.172	0.152	0.000	0.250
31A		11.50	1	Ebb	After	21.1	2.86	32	——	0.380	0.002	——
					Difference	....	−4.00	−44	——	+0.228	+0.002	——
		Noon										
32	Mar. 14	12.00	30	Ebb	Before	3.9	6.43	80	0.236	0.284	0.001	0.169
32A		12.00	30	Ebb	After	21.1	2.57	29	——	0.316	0.001	——
					Difference	....	−3.86	−51	——	+0.032	0.000	——
		A. M.										
41	April 3	9.30	1	Ebb	Before	5.6	7.43	85	0.200	0.164	0.000	0.190
41A		9.30	1	Ebb	After	18.3	4.46	68	0.172	0.196	0.001	0.139
					Difference	....	−2.97	−17	−0.028	+0.032	+0.001	−0.051
42	April 3	9.40	30	Flood	Before	6.1	6.80	83	0.232	0.160	0.001	0.169
42A		9.40	30	Flood	After	18.3	4.32	68	0.172	0.224	0.001	0.089
					Difference	....	−2.48	−15	—0.060	+0.064	0.000	−0.080
		P. M.										
55	April 3	5.20	1	Ebb	Before	6.1	7.57	88	0.340	0.128	0.000	0.230
55A		5.20	1	Ebb	After	20.0	3.89	60	0.228	0.152	0.001	0.099
					Difference	....	−3.68	−28	−0.012	+0.024	+0.001	−0.131
56	April 3	5.30	30	Ebb	Before	6.1	7.57	88	0.404	0.156	0.000	0.160
56A		5.30	30	Ebb	After	20.0	3.78	58	0.344	0.196	0.001	0.169
					Difference	....	−3.79	−30	−0.060	+0.040	+0.001	+0.009
		A. M.										
63	June 13	10.30	1	Ebb	Before	17.2	4.49	74	0.180	0.140	0.002	0.028
63A		10.30	1	Ebb	After	21.1	3.16	54	0.120	0.300	0.003	0.028
					Difference	....	−1.33	−20	−0.060	+0.160	+0.001	0.000
64	June 13	10.40	30	Ebb	Before	17.2	4.39	74	0.324	0.056	0.002	0.028
64A		10.40	30	Ebb	After	21.1	3.27	24	0.160	0.292	0.002	0.018
					Difference	....	−1.12	−50	−0.164	+0.136	0.000	−0.010

TABLE CLXIV—Continued

2—HUDSON RIVER, MIDSTREAM, OFF PIER A—Continued

Sample No.	Date 1912	Hour P. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
77	June 13	4.10	1	Flood	Before	17.2	4.19	69	0.128	0.176	0.002	0.038
77A		4.10	1	Flood	After	21.1	3.16	56	0.156	0.188	0.006	0.034
					Difference		−1.03	−13	−0.028	+0.012	+0.004	−0.002
78	June 13	4.15	30	Flood	Before	16.7	4.19	68	0.168	0.140	0.002	0.068
78A		4.15	30	Flood	After	21.1	2.86	51	0.156	0.256	0.007	0.063
					Difference		−1.33	−17	−0.012	+0.116	+0.005	−0.005
83	July 11	A. M. 9.30	1	Ebb	Before	23.9	2.90	54	0.328	0.412	0.003	0.077
83A		9.30	1	Ebb	After	24.4	1.10	21	0.120	0.500	0.089	0.000
					Difference		−1.80	−33	−0.208	+0.088	+0.086	−0.077
84	July 11	9.40	30	Ebb	Before	23.6	2.80	52	0.276	0.420	0.003	0.077
84A		9.40	30	Ebb	After	24.4	0.60	11	0.136	0.536	0.045	0.000
					Difference		−2.20	−41	−0.140	+0.116	+0.042	−0.077
97	July 11	P. M. 3.05	1	Flood	Before	23.9	3.00	57	0.404	0.436	0.003	0.070
97A		3.05	1	Flood	After	24.4	0.80	15	0.156	0.508	0.133	0.007
					Difference		−2.20	−42	−0.248	+0.072	+0.130	−0.063
98	July 11	3.10	30	Flood	Before	23.9	3.10	59	0.232	0.456	0.003	0.080
98A		3.10	30	Flood	After	24.4	——	—	0.160	0.584	0.064	0.000
					Difference		——	—	−0.072	+0.128	+0.061	−0.080
103	July 24	A. M. 10.00	1	Ebb	Before	21.7	3.10	55	0.312	0.512	0.063	0.037
103A		10.00	1	Ebb	After	23.9	2.00	37	0.132	0.568	0.048	0.062
					Difference		−1.10	−18	−0.180	+0.056	−0.015	+0.025
104	July 24	10.05	30	Ebb	Before	21.7	3.00	55	0.164	0.720	0.065	0.015
104A		10.05	30	Ebb	After	23.9	2.10	40	0.108	0.540	0.160	0.000
					Difference		−0.90	−15	−0.056	−0.180	+0.095	−0.015
117	July 24	P. M. 3.15	1	Ebb	Before	21.7	3.70	66	0.188	0.428	0.071	0.029
117A		3.15	1	Ebb	After	23.9	2.00	32	0.104	0.528	0.080	0.010
					Difference		−1.70	−34	−0.084	+0.100	+0.009	−0.019
118	July 24	3.20	30	Flood	Before	21.1	3.70	67	0.184	0.420	0.073	0.097
118A		3.20	30	Flood	After	23.9	2.10	40	0.116	0.372	0.224	0.000
					Difference		−1.60	−27	−0.068	−0.048	+0.151	−0.097
315	1913 Jan. 9	A. M. 8.00	1	Flood	Before	2.8	6.20	70	0.148	0.108	0.002	0.158
315A		8.00	1	Flood	After	26.7	5.00	95	0.112	0.160	0.012	0.188
					Difference		−1.20	+25	−0.036	+0.052	+0.010	+0.030
325	Jan. 9	11.40	1	Ebb	Before	3.3	5.70	65	0.116	0.128	0.016	0.154
325A		11.40	1	Ebb	After	26.0	4.40	79	0.100	0.152	0.016	0.164
					Difference		−1.30	+14	−0.016	+0.024	0.000	+0.010
335	Feb. 18	10.30	1	Ebb	Before	1.7	5.80	66	0.176	0.228	0.024	0.156
335A		10.30	1	Ebb	After	21.1	4.00	70	0.108	0.300	0.026	0.124
					Difference		−1.80	+4	−0.068	+0.072	+0.002	−0.032
336	Feb. 18	10.35	30	Ebb	Before	1.7	5.80	66	0.132	0.180	0.026	0.084
336A		10.35	30	Ebb	After	21.1	3.40	60	0.108	0.228	0.022	0.108
					Difference		−2.40	−6	−0.024	+0.048	−0.004	+0.024
349	Feb. 18	P. M. 4.50	1	Flood	Before	1.7	5.80	65	0.120	0.160	0.022	0.098
349A		4.50	1	Flood	After	21.1	4.00	71	0.092	0.144	0.024	0.126
					Difference		−1.80	+6	−0.028	−0.016	+0.002	+0.028

TABLE CLXIV—Continued

2—HUDSON RIVER, MIDSTREAM, OFF PIER A—Continued

Sample No.	Date 1913	Hour P. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
350	Feb. 18	4.55	30	Flood	Before	1.7	5.90	67	0.136	0.188	0.022	0.288
350A		4.55	30	Flood	After	21.1	4.00	71	0.088	0.212	0.022	0.258
					Difference	....	−1.90	+4	−0.048	+0.024	0.000	−0.030
394	May 29	2.00	1	Flood	Before	15.3	4.60	70	0.076	0.212	0.030	0.100
394A		2.00	1	Flood	After	21.6	3.63	63	0.096	0.216	0.032	0.098
					Difference	....	−0.97	−7	+0.020	+0.004	+0.002	−0.002
396	May 29	2.30	30	Flood	Before	14.7	4.30	64	0.100	0.212	0.032	0.048
396A		2.30	30	Flood	After	21.6	3.63	63	0.128	0.296	0.040	0.060
					Difference	....	−0.67	−1	+0.028	+0.084	+0.008	+0.012
409	May 29	7.50	1	Ebb	Before	14.4	5.00	75	0.084	0.232	0.027	0.093
409A		7.50	1	Ebb	After	21.6	4.70	80	0.100	0.332	0.028	0.042
					Difference	....	−0.30	−5	+0.016	+0.100	+0.001	−0.051
411	May 29	8.10	30	Ebb	Before	14.4	5.50	84	0.112	0.180	0.030	0.080
411A		8.10	30	Ebb	After	21.6	4.60	80	——	——	——	——
					Difference	....	−0.90	−4	——	——	——	——
415	June 11	A. M. 9.45	1	Ebb	Before	17.7	3.77	60	0.168	0.328	0.036	0.074
415A		9.45	1	Ebb	After	17.8	1.85	30	0.076	0.332	0.046	0.124
					Difference	....	−1.92	−30	−0.092	+0.004	+0.010	+0.050
417	June 11	9.55	30	Ebb	Before	17.5	3.97	65	0.200	0.356	0.038	0.092
417A		9.55	30	Ebb	After	17.7	1.80	29	0.140	0.356	0.050	0.130
					Difference	....	−2.17	−36	−0.060	0.000	+0.012	+0.038
430	June 11	P. M. 1.50	1	Flood	Before	18.4	4.11	68	0.184	0.332	0.040	0.070
430A		1.50	1	Flood	After	18.4	2.08	34	0.124	0.332	0.062	0.098
					Difference	....	−2.03	−34	−0.060	0.000	+0.022	+0.028
432	June 11	2.00	30	Flood	Before	17.2	4.72	77	0.244	0.320	0.040	0.040
432A		2.00	30	Flood	After	17.1	2.09	34	0.136	0.400	0.088	0.072
					Difference	....	−2.63	−43	−0.108	+0.080	+0.048	+0.032

3—ROBBINS REEF, NEAR BELL BUOY

Latitude 40° 39′ 15″. Longitude 74° 03′ 50″.

7	1912 Feb. 27	P. M. 1.15	1	Ebb	Before	2.8	7.14	87	0.338	0.298	0.002	0.188
8		1.25	40	Ebb	Before	2.8	7.28	89	0.352	0.326	0.001	0.219
13	Mar. 4	A. M. 11.35	1	Ebb	Before	1.1	7.14	85	0.192	0.213	0.001	0.139
14		11.30	40	Ebb	Before	1.7	7.14	86	0.196	0.243	0.001	0.139
23	Mar. 5	7.00	1	Flood	Before	0.6	7.43	88	0.264	0.406	0.001	0.179
24		7.05	40	Flood	Before	1.1	7.43	89	0.364	0.332	0.001	0.179
33	Mar. 14	P. M. 12.30	1	Ebb	Before	3.3	6.86	80	0.248	0.180	0.001	0.209
33A		12.30	1	Ebb	After	21.1	3.00	49	——	0.424	0.002	——
					Difference	....	−3.86	−31	——	+0.244	+0.001	——
34	Mar. 14	12.40	40	Ebb	Before	3.9	6.86	85	0.292	0.256	0.001	0.179
34A		12.40	40	Ebb	After	21.1	3.00	53	——	0.268	0.002	——
					Difference	....	−3.86	−32	——	+0.012	+0.001	——

TABLE CLXIV—Continued

3—ROBBINS REEF, NEAR BELL BUOY—Continued

Sample No.	Date 1912	Hour A. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
43	April 3	10.05	1	Flood	Before	6.1	7.28	90	0.196	0.204	0.001	0.179
43A		10.05	1	Flood	After	18.3	4.17	66	0.152	0.228	0.001	0.109
					Difference		−3.11	−24	−0.044	+0.024	0.000	−0.070
44	April 3	10.15	40	Flood	Before	6.1	7.00	90	0.200	0.140	0.001	0.089
44A		10.05	40	Flood	After	18.3	4.60	70	0.116	0.176	0.001	0.089
					Difference		−2.40	−20	−0.084	+0.036	0.000	0.000
		P. M.										
53	April 3	4.50	1	Ebb	Before	6.1	7.28	86	0.220	0.184	0.000	0.230
53A		4.50	1	Ebb	After	20.0	3.33	52	0.184	0.204	0.001	0.089
					Difference		−3.95	−34	−0.036	+0.020	+0.001	−0.141
54	April 3	5.00	40	Ebb	Before	6.1	6.86	85	0.208	0.184	0.001	0.109
54A		5.00	40	Ebb	After	20.0	3.24	53	0.168	0.192	0.001	0.089
					Difference		−3.62	−32	−0.040	+0.008	0.000	−0.020
		A. M.										
65	June 13	11.15	1	Ebb	Before	17.2	4.19	70	0.264	0.144	0.002	0.038
65A		11.15	1	Ebb	After	21.1	3.37	60	0.160	0.352	0.003	0.017
					Difference		−0.82	−10	−0.104	+0.208	+0.001	−0.021
66	June 13	11.20	40	Ebb	Before	16.7	4.19	69	0.192	0.036	0.001	0.039
66A		11.20	40	Ebb	After	21.1	3.27	59	0.128	0.136	0.001	0.030
					Difference		−0.92	−10	−0.064	+0.100	0.000	−0.009
		P. M.										
75	June 13	3.40	1	Flood	Before	17.2	4.29	71	0.168	0.132	0.002	0.028
75A		3.40	1	Flood	After	21.1	3.16	57	0.148	0.308	0.004	0.036
					Difference		−1.13	−14	—0.020	+0.176	+0.002	+0.018
76	June 13	3.45	40	Flood	Before	16.7	4.29	71	0.162	0.100	0.002	0.028
76A		3.45	40	Flood	After	21.1	3.27	59	0.192	0.128	0.006	0.034
					Difference		−1.02	−12	+0.030	+0.028	+0.004	+0.006
		A. M.										
85	July 11	10.10	1	Ebb	Before	23.9	3.00	57	0.344	0.384	0.003	0.070
85A		10.10	1	Ebb	After	24.4	0.70	13	0.140	0.540	0.090	0.070
					Difference		−2.30	−44	−0.204	+0.156	+0.087	0.000
86	July 11	10.15	40	Ebb	Before	23.6	3.10	59	0.200	0.304	0.003	0.060
86A		10.15	40	Ebb	After	24.4	0.80	15	0.108	0.420	0.051	0.000
					Difference		−2.30	−44	−0.092	+0.116	+0.048	−0.060
		P. M.										
95	July 11	2.30	1	Flood	Before	23.9	3.50	67	0.256	0.464	0.003	0.087
95A		2.30	1	Flood	After	24.4	1.00	19	0.152	0.572	0.063	0.000
					Difference		−2.50	−48	−0.104	+0.108	+0.060	−0.087
96	July 11	2.35	40	Flood	Before	23.6	3.50	67	0.224	0.348	0.002	0.058
96A		2.35	40	Flood	After	24.4	1.00	19	0.140	0.372	0.066	0.044
					Difference		−2.50	−48	−0.084	+0.024	+0.064	−0.014
		A. M.										
105	July 24	10.35	1	Ebb	Before	21.7	2.90	53	0.244	0.492	0.054	0.026
105A		10.35	1	Ebb	After	23.9	2.00	38	0.112	0.548	0.106	0.000
					Difference		−0.90	−15	−0.132	+0.056	+0.052	−0.026
106	July 24	10.40	40	Ebb	Before	21.7	2.90	53	0.152	0.380	0.054	0.056
106A		10.40	40	Ebb	After	23.9	2.20	42	0.104	0.480	0.026	0.064
					Difference		−0.70	−11	−0.048	+0.100	−0.028	+0.008

TABLE CLXIV—Continued

3—ROBBINS REEF, NEAR BELL BUOY—Continued

Sample No.	Date 1912	Hour P. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
115	July 24	2.50	1	Flood	Before	21.7	3.60	65	0.160	0.468	0.065	0.015
115A		2.50	1	Flood	After	23.9	2.60	50	0.096	0.504	0.070	0.000
					Difference	....	−1.00	−15	−0.064	+0.036	+0.005	−0.015
116	July 24	2.55	40	Flood	Before	21.1	3.70	67	0.156	0.244	0.039	0.011
116A		2.55	40	Flood	After	23.9	2.60	50	0.080	0.276	0.092	0.000
					Difference	....	−1.10	−17	−0.076	+0.032	+0.053	−0.011
	1913	A. M.										
317	Jan. 9	8.23	1	Flood	Before	2.8	6.30	72	0.140	0.136	0.012	0.148
317A		8.23	1	Flood	After	26.7	4.90	91	0.120	0.324	0.018	0.112
					Difference	....	−1.40	+19	−0.020	+0.188	+0.006	−0.036
		P. M.										
327	Jan. 9	12.15	1	Ebb	Before	3.3	6.00	70	0.144	0.164	0.016	0.154
327A		12.15	1	Ebb	After	3.3	4.80	92	0.076	0.196	0.018	0.192
					Difference	....	+1.20	+22	−0.068	+0.032	+0.002	+0.038
		A. M.										
337	Feb. 18	11.10	1	Ebb	Before	1.7	5.90	68	0.172	0.160	0.026	0.094
337A		11.10	1	Ebb	After	21.1	3.30	41	0.112	0.268	0.028	0.062
					Difference	....	−2.60	−27	−0.060	+0.108	+0.002	−0.032
338	Feb. 18	11.15	40	Ebb	Before	1.7	6.00	69	0.128	0.160	0.026	0.114
338A		11.15	40	Ebb	After	21.1	3.40	61	0.120	0.320	0.024	0.136
					Difference	....	−2.60	−8	−0.008	+0.160	+0.002	+0.022
		P. M.										
347	Feb. 18	4.20	1	Flood	Before	1.7	6.20	71	0.140	0.180	0.024	0.076
347A		4.20	1	Flood	After	21.1	4.00	70	0.068	0.200	0.022	0.078
					Difference	....	−2.20	−1	−0.072	+0.020	+0.002	+0.002
348	Feb. 18	4.25	40	Flood	Before	1.7	6.20	71	0.140	0.172	0.024	0.166
348A		4.25	40	Flood	After	21.1	4.00	70	0.092	0.244	0.022	0.138
					Difference	....	−2.20	−1	−0.048	+0.072	−0.002	−0.028
391	May 29	12.22	1	Flood	Before	15.0	4.60	73	0.152	0.336	0.034	0.066
391A		12.22	1	Flood	After	21.6	2.34	41	0.136	0.344	0.040	0.130
					Difference	....	−2.26	−32	−0.016	+0.008	+0.006	+0.064
393	May 29	1.05	40	Flood	Before	14.4	6.00	95	0.140	0.228	0.024	0.066
393A		1.05	40	Flood	After	21.6	3.90	70	0.144	0.240	0.042	0.058
					Difference	....	−2.10	−25	+0.004	+0.012	+0.018	−0.008
406	May 29	6.45	1	Ebb	Before	15.0	5.00	78	0.084	0.308	0.040	0.050
406A		6.45	1	Ebb	After	21.6	3.40	60	0.116	0.392	0.042	0.088
					Difference	....	−1.60	−18	+0.032	+0.084	+0.002	+0.038
408	May 29	7.15	40	Ebb	Before	14.4	5.10	78	0.112	0.240	0.029	0.050
408A		7.15	40	Ebb	After	21.6	4.43	81	0.104	0.292	0.028	0.052
					Difference	....	−0.67	+3	−0.008	+0.052	−0.001	+0.002
		A. M.										
418	June 11	10.30	1	Ebb	Before	17.7	4.37	71	0.192	0.384	0.040	0.070
418A		10.30	1	Ebb	After	17.8	1.88	31	0.068	0.304	0.046	0.144
					Difference	....	−2.49	−40	−0.124	−0.080	+0.006	+0.074
420	June 11	10.50	40	Ebb	Before	18.5	5.58	93	0.176	0.336	0.036	0.064
420A		10.50	40	Ebb	After	18.4	1.25	21	0.080	0.240	0.042	0.118
					Difference	....	−4.33	−72	−0.096	−0.096	+0.006	+0.054
		P. M.										
433	June 11	2.45	1	Flood	Before	17.8	5.26	89	0.164	0.244	0.024	0.036
433A		2.45	1	Flood	After	17.8	2.63	44	0.124	0.380	0.044	0.094
					Difference	....	−2.63	−45	−0.040	+0.136	+0.020	+0.058

TABLE CLXIV—Continued

3—ROBBINS REEF, NEAR BELL BUOY—Continued

Sample No.	Date 1913	Hour P. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
435	June 11	3.00	40	Flood	Before	17.2	5.83	98	0.148	0.192	0.024	0.046
435A		3.00	40	Flood	After	17.1	3.94	60	0.092	0.360	0.040	0.030
					Difference	....	−1.89	−38	−0.056	+0.168	+0.016	−0.016

4—KILL VAN KULL, MIDSTREAM, OFF SAILORS SNUG HARBOR

Latitude 40° 38′ 50″. Longitude 74° 06′ 07″.

15	1912 Mar. 4	Noon 12.00	1	Ebb	Before	1.1	7.14	83	0.376	0.444	0.001	0.269
16		P. M. 12.05	30	Ebb	Before	1.7	7.14	84	0.276	0.396	0.001	0.289
25	Mar. 5	A. M. 7.30	1	Flood	Before	0.6	7.14	84	0.316	0.432	0.001	0.289
26		7.35	30	Flood	Before	1.1	7.14	85	0.182	0.176	0.001	0.219
35	Mar. 14	P. M. 1.10	1	Ebb	Before	5.0	7.00	82	0.524	0.896	0.002	0.468
35A		1.10	1	Ebb	After	21.1	2.86	46	——	1.044	0.003	——
					Difference	....	−4.14	−36	——	+0.148	+0.001	——
36	Mar. 14	1.20	35	Ebb	Before	5.0	6.86	85	0.416	0.660	0.001	0.309
36A		1.20	35	Ebb	After	21.1	2.57	18	——	0.096	0.003	——
					Difference	....	−4.29	−67	——	+0.300	+0.002	——
45	April 3	A. M. 10.30	1	Flood	Before	6.1	7.00	87	0.212	0.148	0.001	0.129
45A		10.30	1	Flood	After	18.3	4.44	70	0.144	0.204	0.001	0.079
					Difference	....	−2.56	−17	−0.068	+0.056	0.000	−0.050
46	April 3	10.40	35	Flood	Before	6.1	6.86	87	0.212	0.124	0.001	0.029
46A		10.40	35	Flood	After	18.3	4.60	76	0.116	0.168	0.001	0.069
					Difference	....	−2.26	−11	−0.096	+0.044	0.000	+0.040
51	April 3	P. M. 4.30	1	Ebb	Before	6.1	7.28	86	0.216	0.288	0.002	0.148
51A		4.30	1	Ebb	After	18.3	4.31	67	0.176	0.300	0.002	0.148
					Difference	....	−2.97	−19	−0.040	+0.012	0.000	0.000
52	April 3	4.40	35	Ebb	Before	6.1	7.00	85	0.268	0.264	0.002	0.248
52A		4.40	35	Ebb	After	18.3	4.06	64	0.204	0.292	0.002	0.078
					Difference	.......:	−2.94	−21	−0.064	+0.028	0.000	−0.170
67	June 13	A. M. 11.30	1	Ebb	Before	17.2	4.29	70	0.380	0.032	0.004	0.046
67A		11.30	1	Ebb	After	21.1	3.27	57	0.224	0.372	0.004	0.036
					Difference	....	−1.02	−13	−0.156	+0.340	0.000	−0.010
68	June 13	11.35	35	Ebb	Before	17.2	4.29	70	0.350	0.048	0.003	0.047
68A		11.35	35	Ebb	After	21.1	3.37	60	0.144	0.292	0.008	0.052
					Difference	....	−0.92	−10	−0.206	+0.244	+0.005	+0.005
73	June 13	P. M. 3.10	1	Flood	Before	17.2	4.39	73	0.152	0.100	0.002	0.028
73A		3.10	1	Flood	After	21.1	2.96	52	0.120	0.300	0.004	0.026
					Difference	....	−1.43	−21	−0.032	+0.200	+0.002	−0.002
74	June 13	3.15	40	Flood	Before	16.7	4.39	71	0.212	0.120	0.002	0.068
74A		3.15	40	Flood	After	21.1	3.06	54	0.144	0.292	0.008	0.052
					Difference	....	−1.33	−17	−0.068	+0.172	+0.006	−0.016

TABLE CLXIV—Continued

4—KILL VAN KULL, MIDSTREAM, OFF SAILORS SNUG HARBOR—Continued

Sample No.	Date 1912	Hour A. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
87 87A	July 11	10.30 10.30	1 1	Ebb Ebb	Before After	23.9 24.4	3.10 0.80	58 15	0.388 0.216	0.376 0.640	0.005 0.088	0.075 0.000
					Difference	....	−2.30	−43	−0.172	+0.264	+0.083	−0.075
88 88A	July 11	10.40 10.40	35 35	Ebb Ebb	Before After	23.9 24.4	3.10 0.80	58 15	0.372 0.192	0.412 0.496	0.006 0.255	0.074 0.005
					Difference	....	−2.30	−43	−0.180	+0.084	+0.249	−0.069
93 93A	July 11	P. M. 2.00 2.00	1 1	Flood Flood	Before After	23.9 24.4	3.20 1.00	61 19	0.308 0.118	0.400 0.460	0.003 0.066	0.077 0.000
					Difference	....	−2.20	−42	−0.190	+0.060	+0.063	−0.077
94 94A	July 11	2.05 2.05	35 35	Flood Flood	Before After	23.9 24.4	3.20 0.90	61 17	0.268 0.160	0.428 0.484	0.003 0.133	0.087 0.017
					Difference	....	−2.30	−44	−0.108	+0.056	+0.130	−0.070
107 107A	July 27	A. M. 11.15 11.15	1 1	Ebb Ebb	Before After	21.7 23.9	3.40 2.60	61 49	0.308 0.284	0.420 0.516	0.190 0.056	0.000 0.094
					Difference	....	−0.80	−12	−0.014	+0.096	−0.134	−0.094
108 108A	July 24	11.20 11.20	35 35	Ebb Ebb	Before After	21.7 23.9	3.30 2.60	60 49	0.288 0.204	0.416 0.572	0.190 0.120	0.000 0.010
					Difference	....	−0.70	−11	−0.074	+0.156	−0.070	+0.010
113 113A	July 24	P. M. 2.25 2.25	1 1	Flood Flood	Before After	21.7 23.9	3.80 2.50	69 47	0.196 0.144	0.488 0.508	0.099 0.086	0.021 0.014
					Difference	....	−1.30	−22	−0.052	+0.020	−0.013	−0.007
114 114A	July 24	2.30 2.30	35 35	Flood Flood	Before After	21.7 23.9	3.80 2.60	69 50	0.140 0.096	0.452 0.416	0.061 0.060	0.000 0.000
					Difference	....	−1.20	−19	−0.044	−0.036	−0.001	0.000
319 319A	1913 Jan. 9	A. M. 8.40 8.40	1 1	Flood Flood	Before After	2.8 26.7	6.10 4.90	70 91	0.128 0.124	0.180 0.192	0.014 0.018	0.206 0.112
					Difference	....	−1.20	+21	−0.004	+0.012	+0.004	−0.094
329 329A	Jan. 9	P. M. 12.40 12.40	1 1	Ebb Ebb	Before After	3.3 26.7	6.00 4.60	70 94	0.200 0.124	0.228 0.340	0.022 0.032	0.208 0.178
					Difference	....	−1.40	+24	−0.076	+0.112	+0.010	−0.030
339 339A	Feb. 18	A. M. 11.30 11.30	1 1	Ebb Ebb	Before After	1.7 21.1	5.80 3.40	65 60	0.228 0.196	0.488 0.628	0.042 0.042	0.148 0.128
					Difference	....	−2.40	−5	−0.032	+0.140	0.000	−0.020
340 340A	Feb. 18	11.35 11.35	35 35	Ebb Ebb	Before After	1.7 21.1	5.80 3.00	65 53	0.268 0.196	0.440 0.608	0.042 0.040	0.198 0.140
					Difference	....	−2.80	−12	−0.072	+0.168	−0.002	−0.058
345 345A	Feb. 18	P. M. 4.06 4.06	1 1	Flood Flood	Before After	1.7 21.1	6.20 3.60	71 65	0.160 0.112	0.176 0.232	0.024 0.024	0.176 0.156
					Difference	....	−2.60	−6	−0.048	+0.056	0.000	−0.020
346 346A	Feb. 18	4.05 4.05	35 35	Flood Flood	Before After	1.7 21.1	6.30 4.20	72 75	0.184 0.132	0.184 0.252	0.026 0.020	0.194 0.150
					Difference	....	−2.10	+3	−0.052	+0.068	−0.006	−0.044

TABLE CLXIV—Continued

4—KILL VAN KULL, MIDSTREAM, OFF SAILORS SNUG HARBOR—Continued

Sample No.	Date 1913	Hour A. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
388	May 29	11.40	1	Flood	Before	15.6	3.90	61	0.296	0.484	0.064	0.106
388A		11.40	1	Flood	After	21.6	1.80	31	——	——	——	——
					Difference	....	−2.10	−30	——	——	——	——
		Noon										
390	May 29	12.00	35	Flood	Before	15.0	4.90	77	0.244	0.432	0.044	0.066
390A		12.00	35	Flood	After	21.6	2.70	47	——	——	——	——
					Difference	....	−2.20	−30	——	——	——	——
		P. M.										
403	May 29	5.55	1	Ebb	Before	15.0	5.10	86	0.144	0.364	0.044	0.046
403A		5.55	1	Ebb	After	21.6	4.11	73	0.188	0.512	0.060	0.100
					Difference	....	−0.99	−13	+0.044	+0.148	+0.016	+0.054
405	May 29	6.15	35	Ebb	Before	15.0	5.70	90	0.148	0.340	0.040	0.050
405A		6.15	35	Ebb	After	21.6	5.26	93	0.152	0.496	0.054	0.106
					Difference	....	−0.44	+3	+0.004	+0.156	+0.014	+0.056
		A. M.										
421	June 11	11.05	1	Flood	Before	17.7	4.39	73	0.160	0.324	0.036	0.084
421A		11.05	1	Flood	After	17.8	2.37	39	0.092	0.360	0.036	0.124
					Difference	....	−2.02	−34	−0.068	+0.036	0.000	+0.040
423	June 11	11.20	35	Flood	Before	18.5	3.92	66	0.180	0.296	0.036	0.084
423A		11.20	35	Flood	After	18.4	2.33	38	0.080	0.268	0.070	0.090
					Difference	....	−1.59	−28	−0.100	−0.028	+0.034	+0.006
		P. M.										
436	June 11	3.30	1	Ebb	Before	18.4	4.61	78	0.160	0.324	0.040	0.090
436A		3.30	1	Ebb	After	18.4	2.92	49	0.100	0.352	0.060	0.090
					Difference	....	−1.69	−29	−0.060	+0.028	+0.020	0.000
438	June 11	3.45	30	Ebb	Before	17.2	4.33	72	0.104	0.228	0.028	0.102
438A		3.45	30	Ebb	After	17.1	3.56	59	0.096	0.356	0.062	0.088
					Difference	....	−0.77	−13	−0.008	+0.128	+0.034	−0.014

5—NARROWS, BETWEEN FORTS LAFAYETTE AND WADSWORTH

Latitude 40° 36′ 25″. Longitude 74° 02′ 48″.

	1912	P. M.										
5	Feb. 27	12.30	1	Ebb	Before	2.8	7.57	92	0.364	0.290	0.001	0.190
6		12.40	60	Flood	Before	3.3	7.71	98	0.346	0.134	0.001	0.149
17	Mar. 4	1.00	1	Ebb	Before	1.1	7.43	88	0.219	0.223	0.001	0.179
18		1.05	60	Ebb	Before	1.7	7.43	88	0.216	0.223	0.001	0.129
		A. M.										
27	Mar. 5	8.10	1	Flood	Before	0.6	8.15	96	0.230	0.300	0.001	0.119
28		8.15	60	Flood	Before	1.1	8.00	97	0.250	0.272	0.001	0.119
		P. M.										
37	Mar. 14	1.50	1	Ebb	Before	3.9	7.43	88	0.404	0.268	0.001	0.239
37A		1.50	1	Ebb	After	21.1	3.43	57	——	0.416	0.002	——
					Difference	....	−4.00	−31	——	+0.148	+0.001	——
38	Mar. 14	2.00	60	Flood	Before	3.9	7.57	95	0.276	0.172	0.000	0.100
38A		2.00	60	Flood	After	21.1	4.00	71	——	0.176	0.002	——
					Difference	....	−3.57	−24	——	+0.004	+0.002	——

TABLE CLXIV—Continued

5—NARROWS, BETWEEN FORTS LAFAYETTE AND WADSWORTH—Continued

Sample No.	Date 1912	Hour A. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
47	April 3	11.00	1	Flood	Before	6.1	7.71	97	0.204	0.156	0.001	0.139
47A		11.00	1	Flood	After	18.3	4.86	78	0.136	0.164	0.001	0.069
					Difference	....	−2.85	−19	−0.068	+0.008	0.000	−0.070
48	April 3	11.10	60	Flood	Before	6.1	7.57	98	0.200	0.156	0.001	0.109
48A		11.10	60	Flood	After	18.3	4.87	81	0.160	0.148	0.001	0.069
					Difference	....	−2.70	−17	−0.040	−0.008	0.000	−0.040
49	April 3	P. M. 3.50	1	Ebb	Before	6.1	7.43	88	0.192	0.216	0.000	0.150
49A		3.50	1	Ebb	After	18.3	4.17	63	0.108	0.192	0.001	0.149
					Difference	....	−3.26	−25	−0.084	−0.024	+0.001	−0.001
50	April 3	4.00	60	Ebb	Before	6.1	7.14	87	0.208	0.164	0.001	0.239
50A		4.00	60	Ebb	After	18.3	4.06	64	0.104	0.184	0.001	0.129
					Difference	....	−3.08	−23	+0.104	+0.020	0.000	−0.110
69	June 13	A. M. 11.55	1	Ebb	Before	17.2	4.29	71	0.192	0.080	0.002	0.029
69A		11.55	1	Ebb	After	21.1	3.47	62	0.152	0.284	0.002	0.019
					Difference	....	−0.82	−9	−0.040	+0.204	0.000	−0.010
70	June 13	Noon 12.00	60	Ebb	Before	16.7	4.39	73	0.236	0.076	0.002	0.038
70A		12.00	60	Ebb	After	21.1	3.57	64	0.128	0.280	0.003	0.037
					Difference	....	−0.82	−9	−0.108	+0.204	+0.001	−0.001
71	June 13	P. M. 2.30	1	Flood	Before	17.2	4.80	80	0.208	0.136	0.002	0.048
71A		2.30	1	Flood	After	21.1	3.58	68	0.136	0.332	0.003	0.047
					Difference	....	−1.22	−12	−0.072	+0.196	+0.001	−0.001
72	June 13	2.35	60	Flood	Before	16.7	4.90	81	0.296	0.100	0.002	0.028
72A		2.35	60	Flood	After	21.1	3.68	66	0.128	0.224	0.004	0.006
					Difference	....	−1.22	−15	−0.168	+0.124	+0.002	−0.022
89	July 11	A. M. 11.15	1	Ebb	Before	23.9	3.20	61	0.284	0.340	0.003	0.077
89A		11.15	1	Ebb	After	24.4	1.00	19	0.132	0.412	0.094	0.000
					Difference	....	−2.20	−42	−0.152	+0.072	+0.091	−0.077
90	July 11	11.25	60	Ebb	Before	23.6	3.30	63	0.228	0.356	0.003	0.047
90A		11.25	60	Ebb	After	24.4	1.00	19	0.120	0.400	0.035	0.000
					Difference	....	−2.30	−44	−0.108	+0.044	+0.032	−0.047
91	July 11	P. M. 1.30	1	Flood	Before	23.9	3.90	75	0.348	0.232	0.003	0.047
91A		1.30	1	Flood	After	24.4	1.80	35	0.148	0.436	0.064	0.006
					Difference	....	−2.10	−40	−0.200	+0.204	+0.061	−0.041
92	July 11	1.35	60	Flood	Before	23.6	4.00	77	0.236	0.308	0.003	0.087
92A		1.35	60	Flood	After	24.4	1.80	35	0.124	0.380	0.051	0.000
					Difference	....	−2.20	−42	−0.112	+0.072	+0.048	−0.087
109	July 24	A. M. 11.45	1	Ebb	Before	21.7	3.40	62	0.160	0.452	0.054	0.026
109A		11.45	1	Ebb	After	23.9	2.20	42	0.152	0.500	0.066	0.034
					Difference	....	−1.20	−20	−0.008	+0.048	+0.012	−0.008
110	July 24	11.50	60	Ebb	Before	21.7	3.40	62	0.188	0.388	0.070	0.000
110A		11.50	60	Ebb	After	23.9	2.40	46	0.120	0.496	0.020	0.120
					Difference	....	−1.00	−16	−0.068	+0.108	−0.050	+0.120
111	July 24	P. M. 1.50	1	Flood	Before	21.7	3.90	71	0.244	0.456	0.056	0.064
111A		1.50	1	Flood	After	23.9	2.40	46	0.096	0.420	0.050	0.020
					Difference	....	−1.50	−25	−0.148	−0.036	−0.006	−0.044

TABLE CLXIV—Continued

5—NARROWS, BETWEEN FORTS LAFAYETTE AND WADSWORTH—Continued

Sample No.	Date 1912	Hour A. M.	Feet below surface	Tidal current	Incubation	Temp. water Deg. C.	Oxygen		Parts per Million			
							C. C. per litre	Per cent. saturation	Ammonia		Nitrite	Nitrate
									Albuminoid	Free		
112	July 24	1.55	60	Flood	Before	21.1	4.00	73	0.148	0.400	0.052	0.078
112A		1.55	60	Flood	After	23.9	2.60	50	0.096	0.520	0.072	0.058
					Difference	....	−1.40	−23	—0.052	+0.120	+0.020	−0.020
	1913	A. M.										
321	Jan. 9	9.06	1	Flood	Before	3.9	6.80	82	0.144	0.144	0.012	0.208
321A		9.06	1	Flood	After	26.7	5.10	96	0.100	0.204	0.024	0.166
					Difference	....	−1.70	+14	−0.044	+0.060	+0.012	−0.042
		P. M.										
331	Jan. 9	1.30	1	Ebb	Before	3.3	6.10	71	0.148	0.148	0.020	0.160
331A		1.30	1	Ebb	After	26.7	5.10	96	0.076	0.172	0.020	0.240
					Difference	....	−1.00	+25	−0.072	+0.024	0.000	+0.080
		Noon										
341	Feb. 18	12.00	1	Ebb	Before	1.7	6.00	69	0.140	0.228	0.028	0.122
341A		12.00	1	Ebb	After	21.1	3.80	68	0.112	0.256	0.032	0.108
					Difference	....	−2.20	−1	−0.028	+0.028	+0.004	−0.014
		P. M.										
342	Feb. 18	12.05	60	Ebb	Before	1.7	6.10	70	0.124	0.172	0.028	0.192
342A		12.05	60	Ebb	After	21.1	4.00	72	0.108	0.268	0.034	0.176
					Difference	....	−2.10	+2	+0.016	+0.096	+0.006	−0.016
343	Feb. 18	3.25	1	Flood	Before	1.7	6.60	76	0.108	0.196	0.026	0.194
343A		3.25	1	Flood	After	21.1	4.80	86	0.104	0.236	0.024	0.126
					Difference	....	−1.80	+10	−0.004	+0.040	−0.002	−0.068
344	Feb. 18	3.30	60	Flood	Before	1.7	6.70	78	0.164	0.212	0.028	0.182
344A		3.30	60	Flood	After	21.1	4.80	87	0.116	0.236	0.024	0.186
					Difference	....	−1.90	+9	−0.048	+0.024	−0.004	+0.004
		A. M.										
385	May 29	10.05	1	Ebb	Before	15.6	4.40	68	0.172	0.340	0.029	0.081
385A		10.05	1	Ebb	After	21.6	2.57	40	0.116	0.324	0.038	0.042
					Difference	....	−1.83	−28	−0.056	−0.016	+0.009	−0.039
387	May 29	10.30	60	Ebb	Before	14.4	5.60	91	0.124	0.216	0.020	0.030
387A		10.30	60	Ebb	After	21.6	4.41	79	0.092	0.220	0.026	0.054
					Difference	....	−1.19	−12	−0.032	+0.004	+0.006	+0.024
		P. M.										
400	May 29	4.45	11	Flood	Before	15.0	5.20	84	0.100	0.236	0.020	0.060
400A		4.45	11	Flood	After	21.6	4.30	77	0.116	0.324	0.038	0.042
					Difference	....	−0.90	−7	+0.016	+0.088	+0.018	−0.018
402	May 29	5.10	60	Flood	Before	14.4	5.90	94	0.080	0.212	0.040	0.000
402A		5.10	60	Flood	After	21.6	3.81	71	0.092	0.220	0.226	0.054
					Difference	....	−2.09	−23	+0.012	+0.008	+0.014	+0.054
424	June 11	12.05	1	Flood	Before	18.5	4.11	70	0.176	0.268	0.030	0.090
424A		12.05	1	Flood	After	18.4	2.79	47	0.088	0.232	0.032	0.138
					Difference	....	−1.34	−23	−0.088	−0.036	+0.002	−0.048
426	June 11	12.15	60	Flood	Before	16.8	4.15	67	0.144	0.208	0.024	0.086
426A		12.15	60	Flood	After	16.7	3.03	50	0.092	0.320	0.032	0.058
					Difference	....	−1.12	−17	−0.052	+0.112	+0.008	−0.028
439	June 11	4.20	1	Ebb	Before	18.0	5.66	96	0.132	0.228	0.026	0.084
439A		4.20	1	Ebb	After	17.8	3.36	77	0.072	0.284	0.024	0.036
					Difference	....	−2.30	−19	−0.060	+0.056	−0.002	−0.048
441	June 11	4.35	60	Ebb	Before	16.7	6.07	102	0.108	0.188	0.020	0.090
441A		4.35	60	Ebb	After	16.9	3.23	54	0.064	0.280	0.044	0.046
					Difference	....	−2.84	−48	+0.044	+0.092	+0.024	−0.044

ORGANIZATION AND FORCE EMPLOYED

The work of the Commission has been deliberative and executive. The deliberative work has been carried on at meetings of the board, of which there has usually been one each week throughout the year. The executive work has been done chiefly through a staff of trained assistants, acting under the personal direction of the President. The direction of the scientific and technical work by the President has made it unnecessary to employ a Chief Engineer, Chief Chemist or Chief Bacteriologist, and has made it possible for the members of the Commission to keep in immediate contact with every detail of the investigation. To the ability, loyalty and industry of the staff is to be ascribed a large part of the results arrived at.

Over twenty experts have been consulted by the Commission and the reports which they have rendered have contributed materially to place the work upon a broad and authoritative basis.

Acknowledgment is made of assistance and co-operation from the United States Government, especially the U. S. Coast and Geodetic Survey and the Corps of Engineers of the U. S. Army. The New York City officers, particularly the engineers of the bureaus of sewers, have furnished the Commission with much valuable data and criticism.

The assistants employed between January, 1908, when the Commission was reorganized, and May, 1914, have been as follows:

Names.	Title under Civil Service Classifications.	Period of Service.	
		Beginning.	Ending.
Kenneth Allen	Engineer	July 27, 1908	April 30, 1914
D. S. Merritt	Engineer	Nov. 18, 1908	Jan. 15, 1910
Wm. B. Fuller	Engineer	Feb. 4, 1909	June 12, 1909
John H. Gregory	Engineer	Sept. 20, 1910	June 15, 1911
David Loewensohn	Engineer	Feb. 18, 1913	April 18, 1913
W. W. DeBerard	Assistant Engineer	Sept. 20, 1909	Mch. 31, 1910
J. E. Hill	Assistant Engineer	Aug. 10, 1908	Oct. 9, 1908
Geo. H. Shaw	Assistant Engineer	Sept. 1, 1909	April 14, 1910
Donald Belcher	Assistant Engineer	July 29, 1910	May 10, 1911
Charles A. Holden	Assistant Engineer	Aug. 20, 1910	Aug. 10, 1912
Robert B. Morse	Assistant Engineer	Oct. 24, 1910	May 31, 1912
Ernest F. Robinson	Assistant Engineer	Dec. 3, 1912	April 30, 1914
Sidney Smith	Assistant Engineer	Dec. 4, 1912	April 15, 1913
Herbert W. Harvey	Assistant Engineer	Mch. 1, 1913	April 30, 1914
P. F. McClellan	Engineering Assistant	Nov. 27, 1909	April 30, 1910
Harold A. Brown	Engineering Assistant	Nov. 27, 1909	Jan. 15, 1910
R. M. Merriman	Engineering Assistant	Nov. 17, 1909	Nov. 18, 1909
Homer N. Calver	Hydrographic Assistant	June 12, 1913	Aug. 31, 1913
John P. Fox	Statistician	May 28, 1908	Dec. 12, 1909
George Perrine	Statistician	Feb. 1, 1910	Mch. 3, 1910
William R. Copeland	Chemist	Oct. 1, 1911	Feb. 14, 1914
David Morey	Chemist	Aug. 24, 1909	Nov. 27, 1909
Payn B. Parsons	Bacteriologist	Mch. 1, 1909	April 30, 1910
		May 10, 1911	May 16, 1913
Raymond H. Pond	Biologist	Aug. 17, 1908	July 31, 1909
R. N. Hoyt	Biologist	June 20, 1909	Jan. 12, 1910
Max L. Berrey	Draughtsman	Feb. 23, 1909	April 30, 1914
S. R. Kelf	Stenographer	July 27, 1908	April 30, 1910
A. G. Coonan	Stenographer	June 13, 1910	April 30, 1914
Harriet Gellert	Stenographer	June 15, 1913	Nov. 8, 1913
Florence M. Dolan	Stenographer	Dec. 1, 1913	April 30, 1914

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REPORTS OF THE METROPOLITAN SEWERAGE COMMISSION

1. Digest of Data Collected Before the Year 1908 Relating to the Sanitary Condition of New York Harbor; 87 pages; 1909;
2. Report on the Discharge of Sewage from the Proposed Passaic Valley Sewer of New Jersey; 7 pages; May 23, 1910;
3. Report on the Proposed Discharge of Sewage from the Bronx Valley Sewer; 10 pages; July 25, 1910;
4. Sewerage and Sewage Disposal in the Metropolitan District of New York and New Jersey; 550 pages; April 30, 1910;
5. Present Sanitary Condition of New York Harbor and the Degree of Cleanness which is Necessary and Sufficient for the Water; 457 pages; August, 1912;

Preliminary Reports on the Disposal of New York's Sewage:

6. I. Study of the Collection of the Sewage of New York City to a Central Point for Disposal; 16 pages; September, 1911;
7. II. Description of the Four Principal Drainage Divisions in that Part of the Metropolitan Sewerage District which Lies in New York State; 11 pages; November, 1911;
8. III. Study of the Collection and Disposal of the Sewage of the Jamaica Bay Division; 10 pages; November, 1911;
9. IV. Study of the Collection and Disposal of the Sewage of the Upper East River and Harlem Division; 17 pages; July, 1912;
10. V. Study of the Collection and Disposal of the Sewage of the Richmond Division; 21 pages; September, 1912;
11. VI. Study of the Collection and Disposal of the Sewage of the Lower Hudson, Lower East River and Bay Division; 58 pages; January, 1913;
12. VII. Critical Reports of Dr. Gilbert J. Fowler, of Manchester, England, and Mr. John D. Watson, of Birmingham, England, on the Projects of the Metropolitan Sewerage Commission with Special Reference to the Plans Proposed for the Lower Hudson, Lower East River and Bay Division; 33 pages; February, 1913.
13. VIII. Tidal Currents in New York Harbor as Shown by Floats; 46 pages; October, 1913.

14. IX. Rainfall and the Relations Between the Volumes of Domestic Sewage, Storm Water and Tidal Water in New York Harbor; 21 pages; November, 1913.

15. X. Recommendation for a Commission to Construct a System of Main Drainage and Sewage Disposal for New York and Showing the Urgency Therefor; 7 pages; January, 1914.

16. XI. Discharge of Sewage into the Harbors of Boston and New York and a Report by X. H. Goodnough on the Conditions which Led to the Construction of the Main Drainage Systems of Boston and Vicinity; 21 pages; February, 1914.

17. XII. Chemical Oxidation as a Process of Sewage Treatment and a Report by Samuel Rideal on Oxidation Processes Applicable to New York Conditions; 16 pages; March, 1914.

18. XIII. Purification which Can be Effected by Settling Basins and a Report by Karl Imhoff upon the Use of Emscher Tanks in Purifying New York Harbor; 21 pages; March, 1914.

19. XIV. Relation Between the Disposal of the Sewage and the Death Rate and a Report by Walter F. Willcox on the Crude and Corrected Death Rates of New York, London, Berlin and Paris for the Ten Years 1900-1909; 16 pages; March, 1914.

20. XV. Digestion of Sewage by the Harbor Water and the Exhaustion of Dissolved Oxygen, with Tables of Oxygen and Other Chemical Results; 161 pages; March, 1914.

21. XVI. Form of Administration Recommended for the Protection of New York Harbor Against Excessive Sewage Pollution; 12 pages; March, 1914.

22. XVII. Tidal Information in Possession of the Commission and Correspondence on this Subject with the United States Coast and Geodetic Survey; 70 pages; March, 1914.